ESCUELA TÉCNICA SUPERIOR DE INGENIEROS

Proyecto Fin de Carrera

Diseño e implantación de una central eléctrica basada en grupos electrógenos. Estudio de vibraciones torsionales en un eje de acero de alta resistencia.

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"Vísteme despacio que
tengo prisa"
(Napoleón Bonaparte)

A mi familia.

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Y por último, primero a mi familia y luego a mis amigos, que han sufrido conmigo más de lo que debieran a lo largo de todo mi periplo académico universitario.

Miguel Ángel Pérez Rino.

2. Introducción

2.1 Descripción de las prácticas

2.1.1 Estructura general: ubicación del empleo desempeñado

Se pretende introducir en este punto la distribución jerárquica de la empresa en que desarrollé mi trabajo bajo el programa FARO de prácticas en el extranjero.

APS es, en realidad, una consultora energética que trabaja, como se expondrá más adelante, exclusivamente y en la totalidad de los países francófonos africanos. Esta consultoría es a su vez un departamento de una empresa, familiar pero con gran número de asalariados, llamada Delmas Export que desarrolla su trabajo, además de en el campo de la consultoría energética, en el de la venta (y el servicio post-venta) de maquinaria pesada de minería y propulsión de grandes vehículos.

Por otro lado, Delmas Export es el equivalente francés a Finanzauto S.A, es decir, es concesionario exclusivo de Caterpillar en Francia para todo el territorio francófono africano.

Tras esta pequeña introducción aclaratoria se procede, a lo largo del resto del capítulo, a la presentación de las distintas entidades previamente expuestas.

2.1.2 CATERPILLAR. Breve reseña histórica

Fue a principios del año 1880 cuando M.D.Best y B.Holt empezarom a fabricar y a vender, cada uno por su lado, las primeras máquinas agrícolas.

En 1904 la construcción por la sociedad Holt del primer tractor de cadenas va a suponer una revolución y a marcar el comienzo de un gran éxito industrial que continuará hasta nuestros días.

En 1928 surge, de la fusión de Holt y Best, el nombre de Caterpillar Tractor Co. Inmediatamente Caterpillar desarrolla una red de distribuidores independientes para cubrir el mundo entero. JA Delmas Export formará parte de este gran número de concesionarios en el año 1932.

Hoy en día Caterpillar es el primer constructor mundial de material de canteras.

La gama de materiales, más de 300 modelos diferentes, se destina principalmente a las empresas de trabajos públicos, a la industria minera, al mundo agrícola, a la explotación forestal y al tratamiento de residuos, mantenimiento...

Desde hace algunos años Caterpillar se ha desarrollado muy activamente en materia de energía, agrupando todas las actividades relacionadas con motores térmicos, motorización de camiones, barcos, producción de energía eléctrica vía grupos electrógenos, actividades petroleras, motores a gas y turbinas a gas.

Con la compra de la sociedad alemana MAK y Perkins, Caterpillar aumenta sustancialmente su gama de motores. Esta actividad representa actualmente el 37% de las ventas totales.
Algunas cifras actuales son (año 2005): volumen de ventas de 20450 millones USD, 805 millones USD de beneficio y 72004 empleados.

2.1.3 JA DELMAS EXPORT. Breve reseña histórica

JA Delmas Export es una empresa familiar sita en Burdeos, Francia, fundada en 1855 por Jean-Anselme Delmas. Su actividad, orientada desde el principio hacia el continente africano, se dedica a la comercialización de material de obras públicas y material agrícola. El estatus de la empresa es, hoy en día, “Negociante de equipamiento para la construcción”.

En lo que concierne al comienzo de las actividades de la empresa, es en 1828 cuando Philipe Lafargue llega a San Luis, Senegal. Algunos años más tarde, en 1846, se asocia con Joseph Larrieu. Éste último muere en 1860 a causa de un naufragio entre Burdeos y Dakar.

Debido a su falta de descendencia, Philippe Lafargue pone a su subrino JA Delmas a cargo de la dirección de la empresa, que es quien funda la sociedad JA Delmas Export y desarrolla su actividad comercial en 1855, abriendo delegaciones en San Louis. Estas pequeñas delegaciones, convertidas hoy en grandes factorías, proveían productos de primera necesidad cono pañuelos o quincallería y comproban localmente cacahuetes y goma arábiga.

En 1903, el hijo de Jean-Anselme, Philippe, se instala en Dakar, que ya se había convertido en una importante localidad. En 1912 se ve a la cabeza de una importante sociedad implantada por todo el país. A las actividades comerciales tradicionales mencionadas antes se unen ahora, gracias a la compra de los establecimientos Maurin (AEM), una pequeña flota de remolques destinados a la distribución de los productos llegados en barco desde Europa, entre Gorée y el sector de Dakar. Es así que nace el nombre de “Manutention Africaine”.

En 1927 Pierre, hijo de Philippe, a la edad de 26 años, suecede a su padre. Pierre orienta las actividades de la sociedad hacia la técnica, primero con la representación de Renault y, más tarde, en 1932, firma con Caterpillar el "General Agreement". De esta manera JAD se establece en paises en los que no estaba aún presente.

Los hijos de Pierre, Yves y Philippe, toman el mando en 1959, tornando casi toda la actividad hacia los productos Caterpillar.

Desde los años 80 todas las actividades de la empresa se centran en la provisión y mantenimiento de equipos de primera calidad.

Hoy en día, los diferentes equipos de la empresa proponen, no solamente materiales fiables y resistentes, sino que aseguran, además, localmente, asistencia técnica seria y constante, sustitución rápida de piezas y formación adaptada a las necesidades del lugar en cuestión.

Sectores de actividad

La empresa trabaja en 11 paises del oeste africano: Benin, Burkina-Faso, Costa de Marfil, Gambia, Guinea, Liberia, Mali, Mauritania, Nigeria, Senegal y Togo. Estos son también, hoy en día, la única zona de actividad de la empresa, que no tiene actividades comerciales en Europa.

2.1.4 Africa Power Systems

Bajo la presión de Caterpillar de aumentar el volumen de ventas y la eficacia a sus concesionarios en los paises Africanos, JA Delmas Export se asocia en 2002 al otro gran concesionario Caterpillar en África: Tractafric. Esta asociación, llamada en principio GEA (Groupement pour l'Énergie en Afrique) y más tarde y hasta hoy, APS (Afica Power Systems), permitió limitar los costes dado que, las necesidades de Caterpillar implicaban una inversión demasiado grande para cada una de las sociedades por separado. De esta manera, actuando como única sociedad, aumentaron cuantitativamente su poder dentro del grupo Caterpillar y abarcaron, en absoluto monopolio, la totalidad de los 19 paises francófonos africanos.

La actividad de APS está esencialmente vertebrada sobre la venta de grupos electrógenos y motores Caterpillar y Olimpian (filial nacida de la compra de Perkins) así como de diversos materiales de obra civil e instalaciones. El objetivo principal es asegurar la provisión, instalación y mantenimiento de los productos citados anteriormente.

Los productos vendidos por APS son:

- Grupos electrógenos:
  · Producción
  · Auxiliares

- Motores marinos:
  · Propulsion
  · Auxiliares

- Motores industriales:
  · Remotorización
  · Bombeo

- Energía solar:
  · Paneles solares NAPS
  · Baterías y onduladores

· Bombeo solar

- Material eléctrico
  · Inversores de fuentes
  · Armarios de acoplamiento
  · Armarios de potencia MT/BT
  · Transformadores elevadores

2.1.5 Trabajo desarrollado durante las prácticas

El trabajo desarrollado durante seis meses en APS fue, principalmente, el diseño de proyectos de centrales eléctricas “llave en mano”, basadas en grupos electrógenos Caterpillar, desde la concepción a la puesta en servicio, pasando por al aprovisionamiento y la implantación.

2.2 Descripción del proyecto

2.2.1 Introducción

Uno de los proyectos realizados durante mi estancia en APS fue el de la recuperación de la refinería de Samir. En todo este apartado se pretende mostrar el modo de operación utilizado en el desarrollo de cada uno de los proyectos que se acometían en dicha empresa. Se muestra la captura de la oferta, la estructuración del trabajo en los distintos departamentos, el flujo de productos con proveedores propios (Caterpillar) y ajenos (Leroy Somer), los estudios técnicos realizados en cada uno de los campos implicados en un proyecto de tal envergadura y la presentación de los resultados de los mismos a los clientes y, para finalizar, la preparación final y la puesta en marcha de las centrales.

El documento pretende ser más divulgativo que técnico, si bien profundiza en el apartado central, el estudio de vibraciones torsionales, que justifica la lectura de este proyecto en el Departamento de Ingeniería Mecánica de la Escuela Técnica Superior de Ingenieros de Sevilla.

2.2.2 La refinería de SAMIR

El proyecto parte del famoso incendio de la refinería de SAMIR, en la costa de Mohamedía, unos cincuenta kilómetros al sur de Rabat (Marruecos), el 26 de novienmbre de 2002. Debido a la carencia de presas de contención del río Maleb, a menos de un kilómetro del sitio, y de las grandes inundaciones que asolaban la región en la época, la inundación parcial de la fábrica produjo un cortocircuito que, ayudado por la gran cantidad de residuos de hidrocarburos que flotaban en el agua, supuso la destrucción casi completa de la refinería.

La refinería de SAMIR, construida en el año 1959, producía en 2002 2,5 millones de toneladas de gasolina y 1000 millones de metros cúbicos de gas, dando empleo a 1500 personas.

Dada la cantidad de material eléctrico que tenían instalado, la sociedad SAMIR decidió contratar a SIEMENS para la recuperación de su actividad. Estos a su vez, pidieron oferta a APS para lo referente al suministro de energía eléctrica. En los anexos se encuentra el pliego de condiciones presentado por SIEMENS.

2.2.3 Oferta de SIEMENS

Se requería dos grupos electrógenos de 3 MW cada uno, para trabajar en régimen continuo, que generarían la energía eléctrica que demandaban los procesos de la refinería. Podemos ver en el pliego de condiciones que los grupos deberían estar equipados para funcionar en paralelo con la red eléctrica, con otros grupos de producción de electricidad, y ellos sólos como únicos generadores de energía.

Por otra parte, también se hacía demanda de dos grupos de 500 W para permanecer como generadores de emergencia.

2.2.4 Límites de suministro para APS

Como se encuentra relfejado en el pliego de condiciones de SIEMENS, el suministro de APS no comprende nada más allá que los grupos electrógenos y los materiales auxiliares para su alimentación, escape y gobierno.

3 Memoria descriptiva

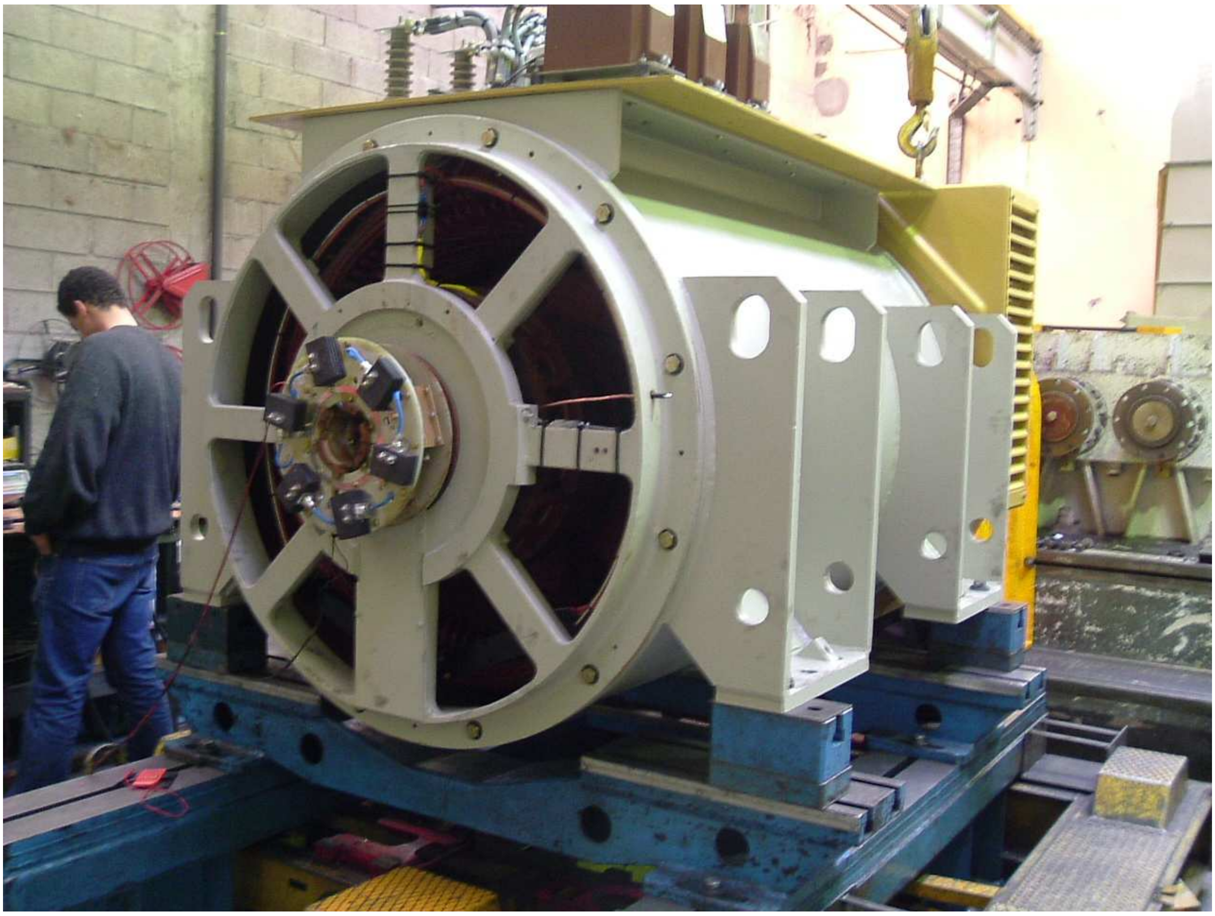
3.1 Proceso de dimensionamiento y selección de grupos

Partiendo de las especificaciones del cliente, se comienza el dimensionamiento del grupo, en primera instancia, en función de la potencia requerida. En este caso, ya que la potencia requerida es de 6 MW y se limita a 2 el número de grupos, es evidente que tenemos que buscar un modelo de 3 MW. Haciendo uso de la “Pocket Ranking Guide Generator Sets” que suministra Caterpillar elegimos el modelo 3612, que sirve 4400 KVA en régimen continuo, 3512 KW con un factor de potencia de 0.8, a 1000 rpm y 50 Hz.

Para elegir el grupo se manejan varias opciones, dependiendo de la propia configuración, del retraso que nos podamos permitir y, evidentemente, de las diferencias de precio. Lo primero que se hace es mirar en nuestra base de datos para ver si tenemos en stock un grupo de

características similares. En nuestro caso, siendo un grupo más potente de lo habitual, no podemos contar con que vayamos a encontrarlo en la base, ya que se aleja bastante de las ventas estándar (en torno a los 1000 kVA). Otra opción, y siempre presentándola como variación a la oferta que se le da al cliente, es buscar un grupo de ocasión, sea en nuestra base de datos o comprándoselo a otro "dealer" de Caterpillar (hay un flujo bastante importante de compra/venta de grupos con Finanzauto S.A., por ejemplo). De nuevo y dada la extraordinaria potencia del grupo demandado, no será evidente encontrar la configuración deseada.
Procedemos entonces al uso de la utilidad CISA (Caterpillar Internet Sales Application) , software suministrado por Caterpillar para configurar un grupo (anexo 2).

Aquí seleccionamos las diferentes opciones que nos ofrece Caterpillar, esto es, configuramos el grupo desde cero. Elegimos el régimen de utilización, la potencia y tensión servidas, los sistemas de control, de refrigeración, de gases de escape, el anclaje, etc. También decidimos todos los aspectos que definen el alternador.



En este caso, y bajo el consejo de la sede de Caterpillar en Suiza (centro de asistencia en Europa), se nos recomienda no configurar el grupo con el alternador de serie, ya que, como antes se indicó, es un grupo que se aleja mucho de los estándares, y se nos dirije a la empresa belga Leroy Somer para suministrarle un alternador. Es en este momento cuando surge la necesidad de realizar el análisis de
vibraciones torsionales en la generatriz, para asegurar la compatibilidad de los dispositivos ensamblados.

Una vez configurado el grupo nos disponemos a hacer inventario de todo el material auxiliar requerido, partiendo por supuesto sobre los planos del sitio donde se va a instalar los grupos.

Se piden los armarios de control a la empresa SULLITRON, el cableado y demás material de transporte de energía eléctrica a MGE, depósitos de combustible y conductos de admisión de combustible y escape de gases (así como silenciadores) a Tubes de Bobigni y el material de aislamiento y atenuación de vibraciones a SULIMER. (anexo 3)

Una vez todo está bien definido y acotado, se dispone a preparar el transporte del material en contenedores de 40’ y se realiza el presupuesto final, considerando los gastos de transporte en base a los INCOTERMS (anexo 4).

Se elabora una oferta escrita y se envía al cliente a la espera de la aceptación o la demanda de modificación de alguno de los aspectos.

3.2 Envío de los grupos a Bélgica

Se envía los grupos a la empresa Leroy Somer para la instalación de los alternadores.
Nosotros, por nuestro lado, hacemos el estudio de vibraciones torsionales del eje, para ver si es adecuado conforme a los valores requeridos por Caterpillar. Para ello, pedimos las especificaciones de los alternadores y del eje y hacemos el análisis correspondiente mediante MATLAB.

3.3 Provisión final e instalación

Se envía el material, un ingeniero y tres técnicos al sitio para la instalación del material vendido, hasta la puesta en marcha de la central y la realización de los test normalizados para dar comienzo al cómputo del tiempo de garantía.

4 Memoria de cálculos y dimensionamientos

4.1 Proceso de selección y configuración de grupo

El primer criterio es, evidentemente, el valor de la potencia demandada. A partir de aquí decidimos el modelo y la cantidad de grupos. Normalmente sobredimensionamos esta potencia en aproximadamente un 10%, para asegurarnos el buen funcionamiento del grupo en cualquiera de las tres configuraciones de uso que le podemos dar (continuo, stand-by o prime power).

Nos encontramos ante una potencia requerida de 3 MW en régimen continuo, esto quiere decir que necesitaremos dimensionar un grupo capaz de dar, al menos, 3000 MWx 1/0.8 (cos phi) = 3750 kVA, luego tenemos que tomar el grupo de 4400 kVA en régimen contínuo, 3612.

Una vez hemos seleccionado el grupo, recurrimos a la utilidad CISA (Caterpillar Internet Sales Application) para configurar todos sus elementos. La aplicación funciona de una manera muy sencilla: divididas en varios campos encontramos todas las opciones disponibles para el grupo, desde la potencia mecánica, régimen de revoluciones y frecuencia hasta el empaquetado para el transporte, pasando por el sistema de control, los radiadores, filtros de aire, conductos de aire y combustible, silenciador, baterías eléctricas, alternador de carga, sistema de arranque, etc.

4.2 Diseño de instalaciones

4.2.1 Circuito combustible

Dimensionamiento depósitos y líneas de transporte

Disponemos un depósito independiente de 1500 L para cada grupo y una línea común con dispositivos de medida para controlar el consumo. Se diseña una línea de ida y vuelta con un coeficiente de consumo por vuelta del 30%, en base al plano de la central. Según una pequeña aplicación programada en Excel, dimensionamos el grosor de las tuberías (que separamos en los tipos: entrada al motor, salida del mismo, líneas principales de ida y vuelta y líneas secundarias de ida y vuelta, teniendo siempre cuidad de las especificaciones de presión a la entrada del motor para considerar las pérdidas de carga en nuestros conductos (anexo 5).

4.2.2 Circuito eléctrico

Potencia

Se dimensiona el cableado de potencia mediante los criterios de intensidad máxima admisible y caída de tensión, mediante un sencillo programa de hoja de cálculo de excel. Si la sección del cable resulta superior a 95 mm^2 se disponen varias líneas en paralelo, para facilitar el transporte y la instalación de las mismas. Luego este cableado se dispone en bandejas en zanja, para una mayor seguridad de la instalación.

Dada la especificación de la salida en tensión a 5500 V, situamos un transformador elevador 400/5500 a la salida de cada grupo. Como hemos sobredimensionado los grupos entorno a un 17% y sabemos que el rendimiento de los transformadores es de un 97%, seguimos teniendo un amplio margen (tenemos que tener al final entorno al 10% de margen para los eventuales picos de sobrecarga y arranque).

Control

De la misma manera, el departamento de eléctricos nos da el tipo y la cantidad de cables a instalar, para el transporte de la información de los grupos a los armarios de control, disponiéndose luego de forma análoga en bandejas en la misma zanja que los cables de potencia. También ellos mismos se encargan de diseñar los armarios de control que regirán el comportamiento de los grupos prime power, así como el eventual cambio a los grupos de seguridad en caso de fallo de los primeros.

Seguridad

Disponemos un circuito de puesta a tierra en las mismas bandejas de soporte del cableado en base a la norma eléctrica correspondiente.

4.2.3 Circuito gases escape

Silenciadores

Recurrimos de nuevo a las características del grupo para definir completamente los caudales de los gases de escape, en todas sus variables termodinámicas, para proceder al diseño del silenciador. A partir de las dimensiones de éste diseñamos el resto del circuito, asegurando los niveles admisibles de ruido establecidos por la norma.

Disponemos los silenciadores fuera del edificio para alcanzar mejores propiedades acústicas, térmicas y estéticas.

Estructuras soporte silenciadores.

Elegimos un perfil H para el soporte de los silenciadores, situados al exterior y anclados al edificio. Partiendo del peso estos (considerando también la masa de gas que tendrán en el interior en régimen nominal) dimensionamos los perfiles para la estructura mostrada en el anexo (anexo 7).

Dispositivo refrigeración de la sala de motores.

Se dispone un sistema de ventiladores en el techo del edificio así como entradas de aire en la pared opuesta a las salidas de los radiadores de los grupos. Para calcular las dimensiones de estos elementos nos basamos en el manual de instalación de grupos de Caterpillar.

5. Análisis de vibraciones torsionales

5.1 Introducción

Normalmente los grupos electrógenos de Caterpillar vienen suministrados con su propio alternador de serie. Sin embargo, el 3612 es un motor normalmente utilizado en la propulsión de barcos y no existe para él en las diferentes opciones de configuración un alternador de serie. En este caso las directrices de Caterpillar fueron acoplarle una generatriz de marca externa y realizar un análisis de vibraciones torsionales para asegurar la fiabilidad del sistema, estableciendo unos valores admisibles de varios factores a medir.

5.2 Descripción teórica del problema

5.2.1. Introducción

Consideremos el caso sencillo representado en la figura 1, sabiendo que todo el conjunto gira según el eje E-E'. El elemento 1 representa el motor que genera un par variable (aunque en la práctica girará a 1000 rpm en régimen estacionario) al girar

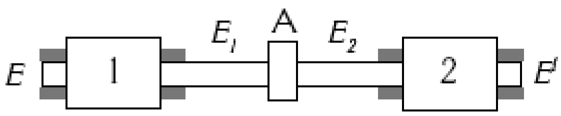


Figura 1

su eje E_1 con una velocidad angular Ω de valor:

$$M_m = A + B \cdot sen(\Omega \cdot t) \qquad (1)$$

El elemento 2 representa el generador, que consume un par determinado M_r, que supondremos constante, para que en el conjunto aparezca un par neto resultante variable con la posición del conjunto caracterizada por el valor de $\Omega{\cdot}t$. Es evidente que, para que el conjunto se mantenga en régimen, ha de ocurrir que :

$$\int_0^{2\pi/\Omega}(A + B{\cdot}sen(\Omega t))dt = M_r{\cdot}2\pi \qquad (2)$$

por lo tanto:

M_r=A mN (3)

Ambos elementos tienen sus ejes E_1 y E_2 conectados mediante el acoplamiento A; si la rigidez torsional de E_1 vale k_1, la de E_2 es k_2 y la del acoplamiento A tiene por valor k_A, podemos sustituir la rigidez de E_1, E_2 y A por K_1 siendo:

$$\frac{1}{K_1} = \frac{1}{k_1} + \frac{1}{k_1} + \frac{1}{k_A} \qquad (4)$$

(por tratarse de un sistema trabajando a torsión todas estas rigideces estarán medidas en mN/radián).

Por otro lado, suponemos que el rotor 1 (de momento de inercia I_1 Kg·m^2) es indeformable igual que el rotor 2 (de momento de inercia I_2 Kg·m^2) y que el conjunto E_1, E_2 y A tiene un momento de inercia despreciable mientras que su rigidez vale K_1 mN/rad. Bajo estas hipótesis simplificadoras, el sistema de la figura 1 queda reducido a un sistema de dos grados de libertad:

· El ángulo $\square_1$ girado por el rotor de momento de inercia I_1.
· El ángulo $\square_2$ girado por el rotor de momento de inercia I_2.

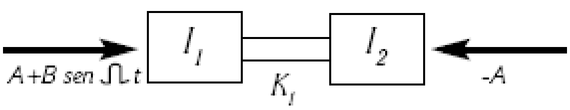


Figura 2

Sobre cada uno de estos rotores actúa respectivamente al par $A + B{\cdot}sen(\Omega t)$ y el par $-A$ como representamos en la figura 2. El problema que deseamos resolver persigue encontrar las vibraciones trsionales que aparecerán en este sistema y analizar su variación en función de los pares aplicados y de los calores de K_1, I_1 e I_2.

5.2.2 Solución clásica y solución mediante análisis modal.

Aplicando la segunda ley de Newton a cada uno de los dos momentos de inercia tendremos:

$$\begin{aligned} A + B{\cdot}sen(\Omega t) + K_1(\varphi_2 - \varphi_1) &= I_1\ddot{\varphi}_1 \\ -A - K_1(\varphi_2 - \varphi_1) &= I_2\ddot{\varphi}_2 \end{aligned} \qquad (5)$$

ecuaciones que podemos escribir de la forma:

$$\begin{aligned} I_1\ddot{\varphi}_1 + K_1\varphi_1 - K_1\varphi_2 &= A + B{\cdot}sen(\Omega t) \\ I_2\ddot{\varphi}_2 - K_1\varphi_1 + K_1\varphi_2 &= -A \end{aligned} \qquad (6)$$

o puestas en forma matricial:

$$\begin{bmatrix} I_1 & 0 \\ 0 & I_2 \end{bmatrix}\begin{bmatrix} \ddot{\varphi}_1 \\ \ddot{\varphi}_2 \end{bmatrix} + \begin{bmatrix} K_1 & -K_1 \\ -K_1 & K_1 \end{bmatrix}\begin{bmatrix} \varphi_1 \\ \varphi_2 \end{bmatrix} = \begin{bmatrix} A + B{\cdot}sen(\Omega t) \\ -A \end{bmatrix} \qquad (7)$$

vemos que para conocer la respuesta del sistema, es decir los valores de φ_1 y φ_2, debemos resolver el sistema de ecuaciones representado por (5), (6) ó (7), sistema en el que las variables φ_1 y φ_2 a determinar aparecen interrelacionadas en ambas ecuaciones. Esto, en un caso tan sencillo como el que estamos considerando, no representa problema alguno; pero, si nos encontrásemos ante un sistema con un número N elevado de grados de libertad, aparecerían N ecuaciones con lasa N incógnitas a determinar acopladas entre sí que deberíamos resolver simultáneamente. Esta dificultad puede obviarse aprovechando la ortogonalidad de los modos naturales de vibración del sistema en estudio que nos permitirá, mediante un sencillo cambio de variables, encontrar N nuevas ecuaciones en las que figure una sola incógnita en cada una de ellas. Encontrado el valor de cada una de estas N incógnitas y deshaciendo el cambio previo resultará ya elemental encontrar los valores de las N variables iniciales que determinan la respuesta del que pretendemos conocer el sistema. Para ello recurrimos al Análisis Modal.

5.2.3 Frecuencias y modos naturales de vibración.

Para conocer la respuesta natural de nuestro sistema liberémoslo de las acciones exteriores que aplicábamos sobre él, por lo que llas ecuaciones (6) quedarán reducidas a:

$$\begin{aligned} I_1\ddot{\varphi}_1 + K_1\varphi_1 - K_1\varphi_2 &= 0 \\ I_2\ddot{\varphi}_2 - K_1\varphi_1 + K_1\varphi_2 &= 0 \end{aligned} \qquad (8)$$

o, en forma matricial:

$$\begin{bmatrix} I_1 & 0 \\ 0 & I_2 \end{bmatrix}\begin{bmatrix} \ddot{\varphi}_1 \\ \ddot{\varphi}_2 \end{bmatrix} + \begin{bmatrix} K_1 & -K_1 \\ -K_1 & K_1 \end{bmatrix}\begin{bmatrix} \varphi_1 \\ \varphi_2 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \qquad (9)$$

podemos escribirlas en forma condensada:

$$[M]\cdot[\ddot{\varphi}] + [K]\cdot[\varphi] = 0 \qquad (10)$$

siendo:

$$[M] = \begin{bmatrix} I_1 & 0 \\ 0 & I_2 \end{bmatrix}$$

la matriz de masas, que vemos resulta diagonal,

$$[\ddot{\varphi}] = [\ddot{\varphi}_1 \ \ddot{\varphi}_2]^T$$

es el vector columna de aceleraciones angulares,

$$[K] = \begin{bmatrix} K_1 & -K_1 \\ -K_1 & K_1 \end{bmatrix}$$

es la matriz de rigideces, que vemos resulta simétrica respecto a la diagonal principal,

$$[\varphi] = [\varphi_1 \ \varphi_2]^T$$

es el vector columna giros de cada uno de los rotores.

Por relacionarse linealmente los valores de las derivadas de los ángulos girado por los rotores con estos ángulos, es elemental ver que la solución de las ecuaciones diferenciales anteriores será de la forma:

$$\begin{aligned} \varphi_1 &= \phi_1 e^{\lambda t} \\ \varphi_2 &= \phi_2 e^{\lambda t} \end{aligned} \qquad (11)$$

que también podemos escribir:

$$\begin{bmatrix} \varphi_1 \\ \varphi_2 \end{bmatrix} = \begin{bmatrix} \phi_1 \\ \phi_2 \end{bmatrix} e^{\lambda t} \qquad (12)$$

o en forma condensada:

$$[\varphi] = [\phi] e^{\lambda t} \qquad (13)$$

A partir de (11), (12) o (13) podemos expresar:

$$\begin{aligned} \ddot{\varphi}_1 &= \lambda^2 \phi_1 e^{\lambda t} \\ \ddot{\varphi}_2 &= \lambda^2 \phi_2 e^{\lambda t} \end{aligned} \qquad (14)$$

o,

$$\begin{bmatrix} \ddot{\varphi}_1 \\ \ddot{\varphi}_2 \end{bmatrix} = \lambda^2 \begin{bmatrix} \phi_1 \\ \phi_2 \end{bmatrix} e^{\lambda t} \qquad (15)$$

o,

$$[\ddot{\varphi}] = \lambda^2 [\phi] e^{\lambda t} \qquad (16)$$

Para encontrar los valores de λ, ϕ_1 y ϕ_2 que permitan encontrar los valores de φ_1 y φ_2 que satisfagan las ecuaciones de partida (8), (9) y (10), y operando a partir de ahora con las ecuaciones en forma matricial, sustituyamos (12) y (15) en (7) y obtendremos :

$$\left[\lambda^2 \begin{bmatrix} I_1 & 0 \\ 0 & I_2 \end{bmatrix} + \begin{bmatrix} K_1 & -K_1 \\ -K_1 & K_1 \end{bmatrix} \right] \begin{bmatrix} \phi_1 \\ \phi_2 \end{bmatrix} e^{\lambda t} = 0 \qquad (17)$$

y, como sabemos que la exponencial no se anula nunca, ha de ocurrir que:

$$\left[\lambda^2 \begin{bmatrix} I_1 & 0 \\ 0 & I_2 \end{bmatrix} + \begin{bmatrix} K_1 & -K_1 \\ -K_1 & K_1 \end{bmatrix} \right] \begin{bmatrix} \phi_1 \\ \phi_2 \end{bmatrix} = 0 \qquad (18)$$

Para evitar la solución trivial $\phi_1 = \phi_2 = 0$, que por (12) conllevaría a que $\varphi_1 = \varphi_2 = 0$, ha de ser nulo el determinante de los coeficientes de ϕ_1 y ϕ_2, es decir :

$$\left| \lambda^2 \begin{bmatrix} I_1 & 0 \\ 0 & I_2 \end{bmatrix} + \begin{bmatrix} K_1 & -K_1 \\ -K_1 & K_1 \end{bmatrix} \right| = 0 \qquad (19)$$

equivalente a :

$$\begin{vmatrix} \lambda^2 I_1 + K_1 & -K_1 \\ -K_1 & \lambda^2 I_2 + K_1 \end{vmatrix} = 0$$

luego :

$$\lambda^4 I_1 I_2 + \lambda^2 \left(I_1 K_1 + I_2 K_1 \right) = 0$$

y de aquí :

$$\lambda^2 \left(\lambda^2 I_1 I_2 + K_1 \left(I_1 + I_2 \right) \right) = 0 \qquad (20)$$

ecuación que permite encontrar los dos únicos valores de λ^2 que hacen posible que φ_1 y φ_2 tengan valores distintos de cero. Estos valores de λ en nuestro caso son :

$$\lambda_1^{\ 2} = 0$$
$$\lambda_2^{\ 2} = \frac{K_1 \left(I_1 + I_2 \right)}{I_1 I_2} \qquad (21), (22)$$

La ecuación (12), conocidos los valores de λ_1 y λ_2, nos permite escribir :

$$\begin{bmatrix} \varphi_1 \\ \varphi_2 \end{bmatrix} = \begin{bmatrix} \phi_{1,1} \\ \phi_{2,1} \end{bmatrix} e^{\lambda t} + \begin{bmatrix} \phi_{1,2} \\ \phi_{2,2} \end{bmatrix} e^{\lambda t} = \begin{bmatrix} \phi_{1,1} \\ \phi_{2,1} \end{bmatrix} I + \begin{bmatrix} \phi_{1,2} \\ \phi_{2,2} \end{bmatrix} e^{\sqrt{\frac{K(I_1+I_2)}{I_1\, I_2}}t} \qquad (23)$$

Las ecuaciones (23) permiten encontrar φ_1 y φ_2 una vez que conozcamos

$$\begin{bmatrix} \phi_{1,1} \\ \phi_{2,1} \end{bmatrix} = \left[\phi_{1,1}\ \phi_{2,1} \right]^T$$
y
$$\begin{bmatrix} \phi_{1,2} \\ \phi_{2,2} \end{bmatrix} = \left[\phi_{1,2}\ \phi_{2,2} \right]^T$$

Conocer estos valores es inmediato aplicando la ecuación (18) para cada uno de los dos valores de λ.

En efecto, y dado que $e^{\lambda \cdot 0} = e^0 = 1$, de (23) obtenemos :

$$(\varphi_1)_{t=0} = \varphi_{10} = \phi_{1,1} + \phi_{2,1}$$
$$(\varphi_2)_{t=0} = \varphi_{20} = \phi_{1,2} + \phi_{2,2} \qquad (24), (25)$$

y sabiendo, además, que mediante la ecuación (18) encontramos para λ_1 una relación entre $\phi_{1,1}$ y $\phi_{2,1}$ y análogamente para λ_2 otra relación entre $\phi_{1,2}$ y $\phi_{2,2}$. Estas relaciones son los llamados modos de vibración natural y que podemos encontrar como hacemos a continuación.

Para obtener el primer modo nos basta sustituir en (18) λ por λ_1 obteniendo :

$$\begin{bmatrix} K_1 & -K_1 \\ -K_1 & K_1 \end{bmatrix} \begin{bmatrix} \phi_{1,1} \\ \phi_{2,1} \end{bmatrix} = 0$$

equivalente a :

$$\phi_{1,1} = \phi_{2,1} \qquad (26)$$

Análogamente, si sustituimos en (18) λ^2 por el valor $\dfrac{K_1(I_1 + I_2)}{I_1 I_2}$ obtendremos el segundo modo que, en nuestro caso, será :

$$\begin{bmatrix} -K_1 \dfrac{I_1 + I_2}{I_1 I_2} I_1 + K_1 & -K_1 \\ -K_1 & -K_1 \dfrac{I_1 + I_2}{I_1 I_2} I_2 + K_1 \end{bmatrix} \begin{bmatrix} \phi_{1,2} \\ \phi_{2,2} \end{bmatrix} = 0$$

equivalente a:

$$\begin{bmatrix} 1 - \dfrac{I_1 + I_2}{I_2} & -1 \\ -1 & 1 - \dfrac{I_1 + I_2}{I_1} \end{bmatrix} \begin{bmatrix} \phi_{1,2} \\ \phi_{2,2} \end{bmatrix} = 0$$

de donde es elemental deducir que

$$\phi_{2,2} = -\frac{I_1}{I_2}\phi_{2,2} \qquad (27)$$

Las ecuaciones (26) y (27) son los dos modos naturales de vibración del sistema que venimos considerando, correspondiendo cada uno a cada una de las frecuencias naturales del mismo. La matriz formada por los modos

$$\phi = \begin{bmatrix} \phi_{1,1} & \phi_{1,2} \\ \phi_{2,1} & \phi_{2,2} \end{bmatrix} \qquad (28)$$

es la llamada Matriz Modal del sistema.

Ya vemos como las ecuaciones (24), (25), (26), (27) permiten encontrar con total facilidad los valores de $\phi_{1,1}$, $\phi_{2,1}$, $\phi_{1,2}$ y $\phi_{2,2}$ como pretendíamos.

Es interesante, pretendiendo facilitar la interpretación física de cada modo de vibración, explicar como podríamos excitar en nuestro sistema cada uno de estos modos viendo que, al hacerlo correctamente, la frecuencia con que los rotores se moverían coincidiría con la frecuencia correspondiente al modo excitado. En nuestro caso las dos posibilidades serían :

· Para el primer modo ($\phi_{1,1}=\phi_{2,1}$), correspondiente a la primera frecuencia $\omega_1^* = \sqrt{\lambda_1} = 0$, los dos rotores giran exactamente el mismo ángulo por lo que no se deforma el eje de constante K_1 que los conecta y todo el conjunto se comportará como un sólido rígido, por lo tanto sin ninguna oscilación.

· Para el segundo modo ($\phi_{2,2} = -\frac{I_1}{I_2}\phi_{2,2}$), correspondiente a la segunda frecuencia $\omega_2^* = \sqrt{\lambda_2} = \sqrt{\frac{K_1(I_1+I_2)}{I_1 I_2}}$ los dos rotores giran en sentido contrario ángulos inversamente proporcionales a sus respectivos momentos de inercia. Por lo tanto, en este modo de vibración, el punto c (figura 3)

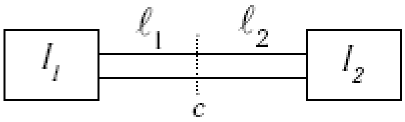


Figura 3

A distancias l_1 y l_2 respectivamente de I_1 e I_2 siendo :

$$\frac{l_1}{l_2} = \frac{I_1}{I_2}$$

quedará en reposo y podremos considerar el movimiento de I_1 como el del sistema de la figura 4 de un grado de libertad y el movimiento de I_2 como el del sistema de la figura 5, también de un grado de libertad.

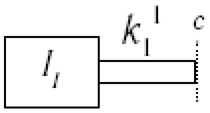


Figura 4

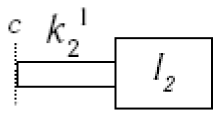


Figura 5

Es evidente que las frecuencias naturales de los sistemas de las figuras 4 y 5 serán, respectivamente :

$$\sqrt{\frac{k_{1,1}}{I_1}} \text{ y } \sqrt{\frac{k_{2,1}}{I_2}}$$

y vamos a demostrar como ambas partes son iguales y de valor

$$\sqrt{\frac{K_1(I_1 + I_2)}{I_1 I_2}}$$

En efecto, sabemos que :

$$\frac{k_{1,1}}{k_{2,1}} = \frac{l_2}{l_1} = \frac{I_1}{I_2} \qquad (29)$$

por lo tanto :

$$\frac{k_{1,1}}{I_1} = \frac{k_{2,1}}{I_2} = \frac{k_{1,1} + k_{2,1}}{I_1 + I_2} \qquad (30)$$

por otro lado, también sabemos que :

$$\frac{1}{k_{1,1}} + \frac{1}{k_{2,1}} = \frac{1}{K_1} = \frac{k_{1,1} + k_{2,1}}{k_{1,1}k_{2,1}} \qquad (31)$$

De (30) y de (31) se deduce directamente que

$$k_{1,1} + k_{2,1} = k_{1,1}\frac{I_1 + I_2}{I_1} = k_{2,1}\frac{I_1 + I_2}{I_2} = \frac{k_{1,1} \cdot k_{2,1}}{K_1} \qquad (32)$$

y de (32) ya es inmediato deducir que:

$$k_{1,1} = K_1\frac{I_1 + I_2}{I_2}$$
$$k_{2,1} = K_1\frac{I_1 + I_2}{I_1} \qquad (33), (34)$$

por lo tanto, las frecuencias naturales de los sistemas de un grado de libertad de las figuras 4 y 5 serán, como habíamos preconizado, ambas iguales y de valor

$$\sqrt{\frac{K_1(I_1 + I_2)}{I_1 I_2}}$$

5.2.4 Ortogonalidad de los modos naturales de vibración

Los modos naturales de vibración, $[\phi_{1,1}\ \phi_{2,1}]^T$ y $[\phi_{1,2}\ \phi_{2,2}]^T$ en nuestro caso, tienen ña propiedad de ser ortogonales tanto respecto a la matriz de masas

$$[M]=\begin{bmatrix} I_1 & 0 \\ 0 & I_2 \end{bmatrix}$$

como respecto a la matriz de rigideces que, en el caso elemental que venimos considerando, vale

$$[K]=\begin{bmatrix} K_1 & -K_1 \\ -K_1 & K_1 \end{bmatrix}$$

Para demostrar esta ortogonalidad consideremos un caso genérico para el que:

· $[M]$ sea la matriz de masas
· $[K]$ sea la matriz de rigideces
· $\lambda_{1,}\ \lambda_2,\ldots,\lambda_i$ los valores de λ que cumplan (19)
· $\phi_1,\phi_2,\ldots,\phi_N$ los N modos naturales de vibración.

Por (18) es evidente que, en este caso general, podemos escribir :

$$\lambda_i^{\ 2}[M]\cdot[\phi_i]=-[K]\cdot[\phi_i] \qquad (35)$$

$$\lambda_j^{\ 2}[M]\cdot[\phi_j]=-[K]\cdot[\phi_j] \qquad (36)$$

si ahora premultiplicamos (35) por $[\phi_i]^T$ y (36) por $[\phi_j]^T$ tendremos :

$$\lambda_i^{\ 2}[\phi_j]^T\cdot[M]\cdot[\phi_i]=-[\phi_j]^T\cdot[K]\cdot[\phi_i] \qquad (37)$$

$$\lambda_j^{\ 2}[\phi_i]^T\cdot[M]\cdot[\phi_j]=-[\phi_i]^T\cdot[K]\cdot[\phi_j] \qquad (38)$$

si transponemos ambos miembros de la ecuación (37) y dado que tanto $[M]$ como $[K]$ son simétricas obtendremos :

$$\lambda_i^2 [\phi_i]^T \cdot [M] \cdot [\phi_j] = -[\phi_i]^T \cdot [K] \cdot [\phi_j] \qquad (39)$$

restando a (39) la ecuación (38) vemos que:

$$\left(\lambda_i^2 - \lambda_j^2\right)[\phi_i]^T \cdot [M] \cdot [\phi_j] = 0 \qquad (40)$$

y como:

$\lambda_i \neq \lambda_j$

necesariamente ha de ocurrir que:

$$[\phi_i]^T \cdot [M] \cdot [\phi_j] = 0 \qquad (41)$$

De (41) vemos como el modo correspondiente a la frecuencia i es ortogonal respecto a la matriz de masas con el modo natural correspondiente a la frecuencia j. De (38) deducimos como también ocurre que:

$$[\phi_i]^T \cdot [K] \cdot [\phi_j] = 0 \qquad (42)$$

luego también los modos son ortogonales respecto a la matriz de rigideces.

Podemos constatar como en nuestro caso ¨(si hacemos $\phi_{1,1} = \phi_{1,2} = 1$):

$$[1 \quad 1] \cdot \begin{bmatrix} I_1 & 0 \\ 0 & I_2 \end{bmatrix} \cdot \begin{bmatrix} 1 \\ -\dfrac{I_1}{I_2} \end{bmatrix} = [I_1 \quad I_2] \cdot \begin{bmatrix} 1 \\ -\dfrac{I_1}{I_2} \end{bmatrix} = [I_1 - I_2] = 0$$

y análogamente:

$$[1 \quad 1] \cdot \begin{bmatrix} K_1 & -K_1 \\ -K_1 & K_1 \end{bmatrix} \cdot \begin{bmatrix} 1 \\ -\frac{I_1}{I_2} \end{bmatrix} = [K_1 - K_1 \quad -K_1 + K_1] \cdot \begin{bmatrix} 1 \\ -\frac{I_1}{I_2} \end{bmatrix} = 0$$

Si en el proceso anterior hiciésemos i=j la ecuación (40) se convertiría en

$$\left(\lambda_i^2 - \lambda_i^2\right)[\phi_i]^T \cdot [M] \cdot [\phi_i] = 0 \qquad (43)$$

pero como

$$\lambda_i^2 - \lambda_i^2 = 0$$

no tiene por qué cumplirse que

$$[\phi_i]^T \cdot [M] \cdot [\phi_i] = 0 \qquad (44)$$

sea nulo. Tampoco ocurrirá que:

$$[\phi_i]^T \cdot [K] \cdot [\phi_i] = 0 \qquad (45)$$

A las expresiones (44) y (45) se las conoce como Masa i-ésima Generalizada y como Rigidez i-ésima Generalizada, respectivamente. En el caso sencillo que venimos estudiando ocurre que:

· La primera masa modal generalizada es: $I_1 + I_2$

· La segunda masa modal generalizada es: $I_1 \frac{I_1 + I_2}{I_2}$

· La primera rigidez modal generalizada es: 0

· La segunda rigidez modal generalizada es: $K_1 \left(\frac{I_1 + I_2}{I_2} \right)^2$

Nótese como:

$$\sqrt{\frac{0}{I_1 + I_2}} = 0 = \omega_1$$

y como:

$$\sqrt{\frac{K_1\left(\frac{I_1 + I_2}{I_2}\right)^2}{I_1 \frac{I_1 + I_2}{I_2}}} = \sqrt{\frac{K_1(I_1 + I_2)}{I_1\, I_2}} = \omega_2$$

valores que coinciden con las frecuencias naturales de cada uno de los dos modos naturales de vibración de nuestro problema.

5.2.5. Análisis modal

Si en la ecuación (7), representativa del movimiento en nuestros dos rotores, sustituimos φ_1 y φ_2 por:

$$\begin{bmatrix} \varphi_1 \\ \varphi_2 \end{bmatrix} = \begin{bmatrix} \phi_{1,1} & \phi_{1,2} \\ \phi_{2,1} & \phi_{2,2} \end{bmatrix} \cdot \begin{bmatrix} q_1 \\ q_2 \end{bmatrix} \qquad (46)$$

o, puesto en forma condensada, hacemos el cambio de variable :

$$[\varphi] = [\phi] \cdot [q] \qquad (47)$$

en que :

· $[\varphi]$ es el vector columna de los giros de I_1 e I_2

· $[\phi]$ es la matriz modal como la definimos en (28)

· $[q]$ es un vector columna de dos nuevas variables funciones del tiempo

Tendremos en forma matricial que :

$$[M][\phi][\ddot{q}]+[K][\phi][q]=[P] \qquad (48)$$

Si llamamos

$$[P]=\begin{bmatrix} P_1 \\ P_2 \end{bmatrix}=\begin{bmatrix} A+Bsen\Omega t \\ -A \end{bmatrix} \qquad (49)$$

y si premultiplicamos ahora ambos miembros de (48) por la traspuesta de la matriz modal tendremos :

$$[\phi]^T[M][\phi][\ddot{q}]+[\phi]^T[K][\phi][q]=[\phi]^T[P] \qquad (50)$$

La ecuación (50) en nuestro caso sería :

$$\begin{bmatrix} 1 & 1 \\ 1 & -\frac{I_1}{I_2} \end{bmatrix}\cdot\begin{bmatrix} I_1 & 0 \\ 0 & I_2 \end{bmatrix}\cdot\begin{bmatrix} 1 & 1 \\ 1 & -\frac{I_1}{I_2} \end{bmatrix}\cdot\begin{bmatrix} \ddot{q}_1 \\ \ddot{q}_2 \end{bmatrix}+\begin{bmatrix} 1 & 1 \\ 1 & -\frac{I_1}{I_2} \end{bmatrix}\cdot\begin{bmatrix} K_1 & -K_1 \\ -K_1 & K_1 \end{bmatrix}\cdot\begin{bmatrix} 1 & 1 \\ 1 & -\frac{I_1}{I_2} \end{bmatrix}\cdot\begin{bmatrix} q_1 \\ q_2 \end{bmatrix}=$$
$$=\begin{bmatrix} 1 & 1 \\ 1 & -\frac{I_1}{I_2} \end{bmatrix}\cdot\begin{bmatrix} A+Bsen\Omega t \\ -A \end{bmatrix} \qquad (51)$$

y, operando, esta última expresión se convierte en:

$$\begin{bmatrix} I_1+I_2 & 0 \\ 0 & I_1\frac{I_1+I_2}{I_2} \end{bmatrix}\cdot\begin{bmatrix} \ddot{q}_1 \\ \ddot{q}_2 \end{bmatrix}+\begin{bmatrix} 0 & 0 \\ 0 & K_1\left(\frac{I_1+I_2}{I_2}\right)^2 \end{bmatrix}\cdot\begin{bmatrix} q_1 \\ q_2 \end{bmatrix}=\begin{bmatrix} Bsen\Omega t \\ A+Bsen\Omega t+\frac{I_1}{I_2}A \end{bmatrix}=$$
$$=\begin{bmatrix} Bsen\Omega t \\ A\frac{I_1+I_2}{I_2}+Bsen\Omega t \end{bmatrix} \qquad (52)$$

en donde vemos como todas las matrices del primer miembro son diagonales como tenía que ocurrir recordando la ortogonalidad de los modos naturales de vibración. Por ser diagonales las matrices del primer miembro las dos ecuaciones del sistema (52) se convierten en dos ecuaciones con las variables q_1 y q_2 completamente desacopladas con lo que el sistema de dos grados de libertad inicial queda configurado como dos sistemas cada uno de un grado de libertad (q_1 y q_2).

Estos dos sistemas serán :

· $$(I_1 + I_2)\ddot{q}_1 = Bsen\Omega t \qquad (53)$$

sistema que podemos representar como hacemos en la figura 6.

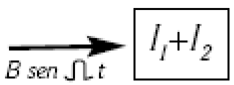


Figura 6

· $$I_1 \frac{I_1 + I_2}{I_2}\ddot{q}_2 + K_1\left(\frac{I_1 + I_2}{I_2}\right)^2 q_2 = A\frac{I_1 + I_2}{I_2} + Bsen\Omega t \qquad (54)$$

equivalente a:

$$I_1\ddot{q}_2 + K_1\frac{I_1 + I_2}{I_2}q_2 = A + \frac{BI_2}{I_1 + I_2} + Bsen\Omega t \qquad (55)$$

sistema que podemos representar según la figura 7.

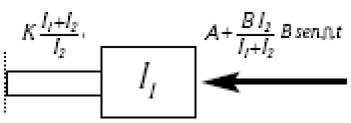


Figura 7

Los valores de q_1y q_2, en régimen permanente, solución de estos sitemas serán :

$$q_1 = \frac{B}{(I_1 + I_2)\Omega^2} sen\Omega t \qquad (55)$$

$$q_2 = \frac{AI_2}{K_1(I_1 + I_2)} + \frac{\frac{BI_2}{I_1 + I_2}}{K_1 \frac{I_1}{I_1 + I_2} - I_1\Omega^2} sen\Omega t \qquad (56)$$

por lo tanto, los ángulos φ_1 y φ_2 girados por cada uno de los dos rotores, podremos ya encontrarlos recordando que

$$\begin{bmatrix} \varphi_1 \\ \varphi_2 \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 1 & -\frac{I_1}{I_2} \end{bmatrix} . \begin{bmatrix} q_1 \\ q_2 \end{bmatrix}$$

es decir

$$\varphi_1 = q_1 + q_2 = \frac{B}{(I_1 + I_2)\Omega^2} + \frac{AI_2}{K_1(I_1 + I_2)} + \frac{B}{K_1\left(\frac{I_1 + I_2}{I_2}\right)^2 - I_1 \frac{I_1 + I_2}{I_2}\Omega^2} sen\Omega t \qquad (57)$$

$$\varphi_2 = q_1 - \frac{I_1}{I_2} q_2 = \frac{B}{(I_1 + I_2)\Omega^2} - \frac{AI_1}{K_1(I_1 + I_2)} - \frac{I_1}{I_2} \frac{B}{K_1\left(\frac{I_1 + I_2}{I_2}\right)^2 - I_1 \frac{I_1 + I_2}{I_2}\Omega^2} sen\Omega t \qquad (58)$$

La deformación a torsión del eje evidentemente será:

$$T=\varphi_1-\varphi_2=\frac{A}{K_1}+\left(1+\frac{I_1}{I_2}\right)\cdot\frac{B}{K_1\left(\frac{I_1+I_2}{I_2}\right)^2-I_1\frac{I_1+I_2}{I_2}\Omega^2}sen\Omega t=$$

$$=\frac{A}{K_1}+\frac{I_1+I_2}{I_2}\frac{B}{K_1\left(\frac{I_1+I_2}{I_2}\right)^2-\frac{I_1}{I_2}(I_1+I_2)\Omega^2}sen\Omega t= \qquad (59)$$

$$=\frac{A}{K_1}+\frac{B}{K_1\frac{I_1+I_2}{I_2}-I_1\Omega^2}sen\Omega t$$

La interpretación física de cada uno de los términos en la ecuación (59) es elemental:

El término $\frac{A}{K_1}$ es la deformación torsional elástica debido al par constante que, generado en el motor y consumido en la máquina, mantiene el sistema en régimen.

El término

$$\frac{B}{K_1\frac{I_1+I_2}{I_2}-I_1\Omega^2}sen\Omega t$$

es la deformación variable en el eje como consecuencia del par variable que se transimite a través del mismo, deformación cuya amplitud sería nula si K_1 valiera infinito y sería finita si

$$\Omega^2=\frac{K_1(I_1+I_2)}{I_1I_2}$$ (por estar en resonancia con ω_2).

Por otro lado, el par variable transmitido por el eje sería :

$$P=\frac{K_1B}{K_1\frac{I_1+I_2}{I_2}-I_1\Omega^2}sen\Omega t \qquad (60)$$

De la expresión (60) deducimos que :

· Este par para $K=\infty$, valdría

$$Par_{K=\infty} = \frac{BI_2}{I_1 + I_2} sen\Omega t \qquad (61)$$

Como podemos deducir aplicando al sistema en estudio las ecuaciones de la mecánica del Sólido Rígido :

· Sería infinita la amplitud del par para

$$\Omega = \sqrt{\frac{K_1(I_1 + I_2)}{I_1 I_2}}$$

· Si $\Omega' = \sqrt{2}\omega_2$, es decir si

$$\Omega' = \sqrt{2\frac{K_1(I_1 + I_2)}{I_1 I_2}}$$

el par tendría por expresión :

$$Par = \frac{K_1 B}{K_1 \frac{I_1 + I_2}{I_2} - I_1 \frac{2K_1(I_1 + I_2)}{I_1 I_2}} sen\Omega t = -\frac{BI_2}{I_1 + I_2} sen\Omega t = \qquad (62)$$
$$= \frac{BI_2}{I_1 + I_2} sen(\Omega t - \pi)$$

En este caso el módulo del par coincide en valor con el transmitido para $K = \infty$ pero está decalado 180º.

5.2.6. Conclusiones

Hemos visto como un sistema de 2 grados de libertado lo hemos resuelto, gracias al análisis modal, mediante el estudio de dos sitemas totalmente desacoplados de un grado de libertad cada uno. En el caso de que deseásemos estudiar un sistema general con N grados de libertad el proceso sería exactamente el mismo apareciendo los siguientes cambios :

1) Las matrices $[M]$ y $[K]$, diagonal la primera y simétrica la segunda, tendrían N filas y N columnas.

2) Aparecerían N frecuencias naturales y N modos naturales de vibración. Estos seguirían siendo ortogonales respecto a la matriz de masas y respecto a la matriz de rigideces.

3) La matriz modal $[\phi]$ definida por los N modos naturales, tendría N columnas y cada una constaría de N elementos.

4) El número de masas generalizadas sería N y análogamente sería N el número de rigideces generalizadas.

5) El problema quedaría reducido, al hacer el cambio de variables $[\varphi][\phi][q]$, a resolver N ecuaciones de las que deduciríamos en cada una de ellas el valor q_i correspondiente y econtraríamos los valores correspondientes de las variables a determinar $[\varphi]$, mediante la transformación

$$[\varphi]=[\phi][q]$$

Siendo :

$[\varphi]$ el vector columna a encontrar.

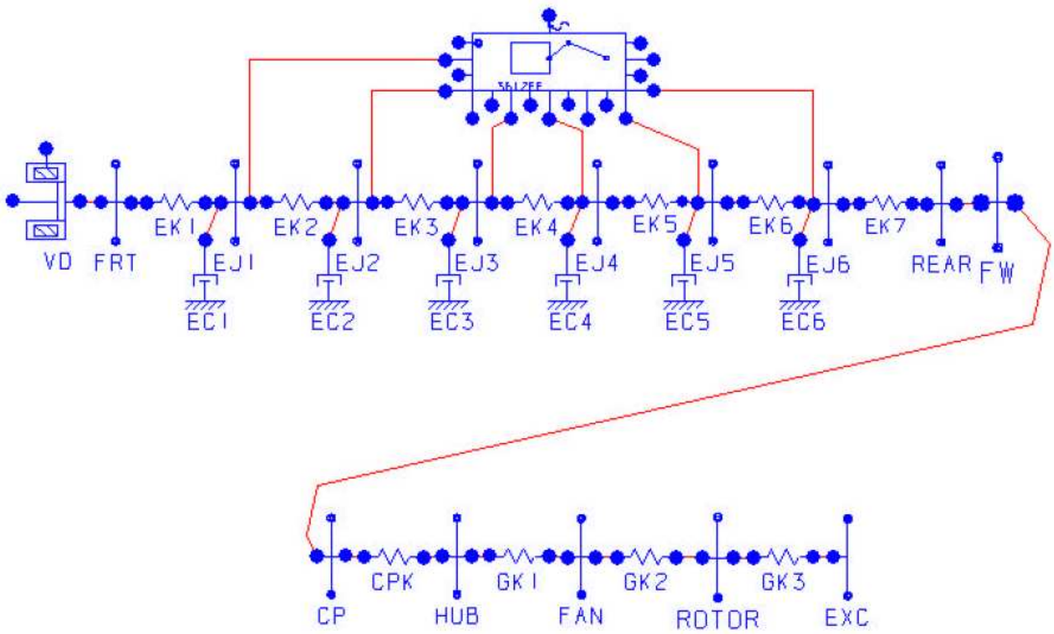
$[\phi]$ la matriz modal ya definida en el proceso.

$[q]$ el vector columna calculado en (5).

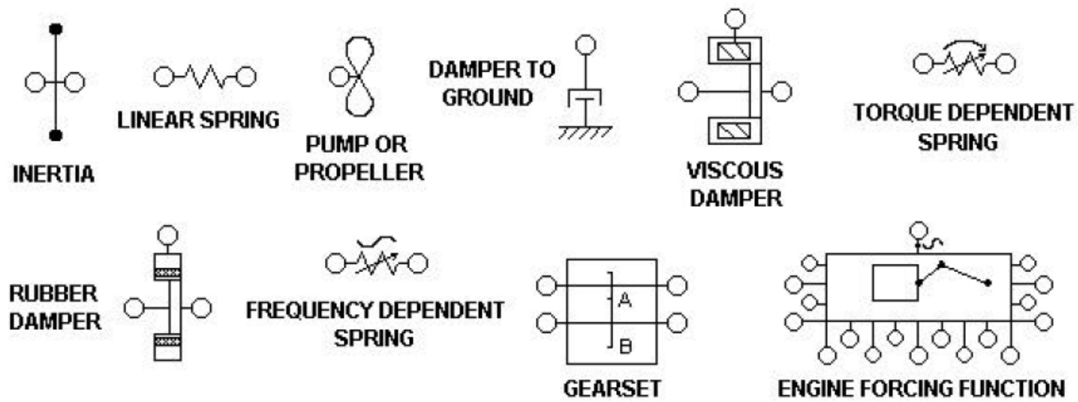
5.3 Problema en estudio

5.3.1 Modelo

Siempre bajo las directrices marcadas por Caterpillar planteamos el siguiente modelo, para cada una de las partes que integran la totalidad del sistema :



donde :



Los valores de las inercias de cada una de las masas son :

Caterpillar Inc.

Mass-Elastic Data

Damper Parameters

Damper Type	Housing Inertia Nms^2	Ring Inertia Nms^2	Effective Stiffness MNm/rad	Damping Nms/rad
Viscous	12.26	29.20	2.85	7000

MASS-ELASTIC DATA

MASS ID	MASS NAME	INERTIA (N*m*sec^2)	SPRING ID	STIFFNESS (MN*m/rad)	DIAMETER (mm)
VD		2.686E+01		0.000E+00	0.000E+00
FRT		5.645E+00	EK1	6.780E+01	2.160E+02
EJ1		1.700E+01	EK2	4.011E+01	2.160E+02
EJ2		1.632E+01	EK3	4.011E+01	2.160E+02
EJ3		1.632E+01	EK4	4.011E+01	2.160E+02
EJ4		1.632E+01	EK5	4.011E+01	2.160E+02
EJ5		1.632E+01	EK6	4.011E+01	2.160E+02
EJ6		1.700E+01	EK7	6.780E+01	2.160E+02
REAR		5.826E+00		0.000E+00	0.000E+00
FW		7.490E+01		0.000E+00	0.000E+00
CP		5.900E+01	CPK	1.600E+00	0.000E+00
HUB		2.030E+01	GK1	6.580E+01	2.000E+02
FAN		4.600E+01	GK2	4.309E+01	2.100E+02
ROTOR		4.287E+02	GK3	9.390E+01	2.600E+02
EXC		5.750E+00		0.000E+00	0.000E+00

System Damping

Component ID	Damping Nms/rad
EC1 – EC6	531 each

5.3.2 Límites admisibles

Los valores límites marcados por Caterpillar son :

System Data

Engine model 3612 rated at 3700 bkW, 1000 rpm operating speed

Engine Damper:	Caterpillar Part No. 7W0127
Engine Flywheel:	Caterpillar Part No. 9Y6182
Flywheel Ring:	Caterpillar Part No. 9Y1851
Coupling:	Caterpillar Part No. 1470076
Generator:	Leroy Somer LSA56 L7/6p - MT, Dwg. No. P1 256 0826

Recommended Limits

Torsional vibration limits are as follows:

Amplitude at front of engine crankshaft:	+/- 1.00 degrees for 0.5 and 1.0 orders
	+/- 0.25 degrees for 1.5 order
	+/- 0.15 degrees for orders above 1.5
Stress in engine crankshaft:	+/- 21.0 MPa for individual orders
Stress in generator shaft:	+/- 34.5 MPa for individual orders

5.3.3 Conlusiones

Se observa en la siguiente tabla que ninguna de las masas que componen el sistema supera los valores máximos admisibles establecidos por Caterpillar :

Single Order Results		Order	Predicted	Permissible Limit
FRT	Absolute Amplitude (deg)	0.5	0.016	1.00
	Absolute Amplitude (deg)	1.0	0.033	1.00
	Absolute Amplitude (deg)	1.5	0.095	0.25
	Absolute Amplitude (deg)	3.0	0.009	0.15
	Absolute Amplitude (deg)	4.5	0.107	0.15
	Absolute Amplitude (deg)	6.0	0.043	0.15
EK5	Vibratory Stress (MPa)	0.5	1.62	21.0
	Vibratory Stress (MPa)	1.0	12.99	21.0
	Vibratory Stress (MPa)	1.5	12.97	21.0
	Vibratory Stress (MPa)	3.0	2.07	21.0
	Vibratory Stress (MPa)	4.5	10.94	21.0
	Vibratory Stress (MPa)	6.0	3.21	21.0
GK1	Vibratory Stress (MPa)	0.5	0.06	34.5
	Vibratory Stress (MPa)	1.0	0.75	34.5
	Vibratory Stress (MPa)	1.5	1.52	34.5
	Vibratory Stress (MPa)	3.0	0.59	34.5
	Vibratory Stress (MPa)	4.5	1.00	34.5
	Vibratory Stress (MPa)	6.0	0.17	34.5
	Vibratory Stress (MPa)	7.5	0.30	34.5
	Vibratory Stress (MPa)	8.0	0.45	34.5

Combined Order Results		Predicted	Permissible Limit
VD	Power Absorbed (kW/m^2)	4.0	5.7
CPK	Maximum Torque (Nm)	41522	134000
	Vibratory Torque (Nm)	5471	25200
	Nominal Torque (Nm)	35332	63000
	Power Loss (kW)	0.15	1.06

Single Order Misfire Results		Order	Predicted	Permissible Limit
FRT	Absolute Amplitude (deg)	0.5	0.081	1.00
	Absolute Amplitude (deg)	1.0	0.510	1.00
EK5	Vibratory Stress (MPa)	0.5	4.21	21.0
	Vibratory Stress (MPa)	1.0	16.50	21.0
GK1	Vibratory Stress (MPa)	0.5	3.79	34.5
	Vibratory Stress (MPa)	1.0	11.72	34.5

Combined Order Misfire Results		Predicted	Permissible Limit
VD	Power Absorbed (kW/m^2)	4.0	5.7
CPK	Maximum Torque (Nm)	61179	134000
	Vibratory Torque (Nm)	24186	25200
	Nominal Torque (Nm)	35332	63000
	Power Loss (kW)	2.02	1.06
Engine misfire may cause significant torsional vibration in the coupling, as indicated by high vibratory torque and power loss levels. This vibration would cause the coupling rubber elements to warm, changing their elastic properties. See warm coupling results beginning on page 25 for a more accurate representation of engine misfire behavior.			

Aunque los resultados de la simulación fueron satisfactorios, mi estancia en la empresa concluyó antes de la implantación final del proyecto, con lo que no se puede ofrecer una comparación con los resultados de las pruebas in situ. De todos modos, tanto el rigor científico perseguido a lo largo de todo el trabajo como los valores de los resultados arrojados por el mismo, deberían dejar un margen suficientemente amplio como para no encontrarse con ningún problema en la realidad .

6 Anexos

Anexo 1: Pliego de condiciones

REQUISITION D'ACHAT Nº RTH 01

OBJET: Groupes diesel de production d'électricité
2x3 MW- 5500 V- 50 Hz
2x0,5 MW- 220 V- 50 Hz

Généralités:
La présente réquisition concerne la fourniture, l'installation et la mise en service, clé en main, d'une centrale électrique basée sur des groupes diesel de production d'électricité:

- Groupes électrogènes de production continue :
  Cette installation est d'une puissance totale de 6 MW, service continu, et se composera de deux groupes de 3 MW chacun, et aura les caractéristiques spécifiées dans la partie A/ ci-après.
- Groupes électrogènes de secours :
  Cette installation sera d'une puissance totale de 1 MW, composée de deux groupes électrogènes de secours, dont les caractéristiques sont spécifiées dans la partie B/ ci-après.

A/ GROUPES ELECTROGENES 2x3 MW- 5500V- 50 Hz- 3Φ

Les groupes diesel seront conçus pour assurer une production continue et de secours. Ils doivent être équipés pour fonctionner en parallèle avec le réseau électrique publique, avec d'autres groupes de production d'électricité, et également en flot.

La mise en marche des groupes électrogènes diesel s'opérera en premier lieu dans la salle de commande. Le mode de fonctionnement est manuel avec synchronisation automatique, basée sur la commande par touches d'opérateur. Les équipements auxiliaires sont commandés à partir de panneaux de commande locaux, installés à coté des équipements respectifs.

L'installation sera conçue pour fonctionner uniquement au GAS OIL.

1) Conditions du site :

Température ambiante maximale extérieur	: 45°C
Température maximale ambiante, salle des moteurs	: 50°C
Altitude maximale au-dessus du niveau de la mer	: 3 mètres
Humidité relative maximale	: 90%
Pouvoir calorifique	: 42.700 kJ/kg

2) Disposition :
Les groupes électrogènes diesel seront installés sur des fondations en béton dans un bâtiment dis salle des moteurs. Les filtres à air de combustion, les silencieux des gaz d'échappement et les réservoirs du GAS OIL, seront installés à l'extérieur du bâtiment principal.

Les groupes électrogènes seront fournis avec des pompes de pré lubrification et une unité de préchauffage à commande électrique, permettant la mise en ligne de ses unités avec préavis court.

3) Caractéristiques principales :

La puissance électrique dans sa totalité est produite par deux groupes électrogènes équipés de moteurs diesel fonctionnant au GAS OIL, avec les caractéristiques électriques ci-après :

Puissance nominale installée de la centrale	: 2x3000	kWe
Puissance nette de sortie de la centrale	: 2x3750	kVA
Tension générateur et secteur	: 5500	V, ajust ! 5%
Fréquence	: 50	Hz
Tension auxiliaire	: 400	V CA
	110/48/24	V CC

4) Moteur diesel :

Le moteur diesel équipant le groupe électrogène doit être un Turbo Diesel à 4 temps suralimenté.
Les soumissionnaires doivent joindre à leur offre les caractéristiques détaillées du moteur proposé.
La consommation spécifique, selon les conditions du site et suivant les conditions de référence de la norme ISO 3046/1 doivent être fournies, à differents régimes (100%, 75% et 50% de la charge).

5) Alternateur :

L'alternateur est un générateur synchronique autorégulateur sans balais dont les caractéristiques principales sont :

Puissance admissible en service continu	: 3750	kVA
Facteur de puissance minimal	: 0,8	
Tension nominale	: 5,5	kV
Classe d'échauffement	: F	
Classe d'isolation	: F	
Classe de protection	: IP 23, minimal	
Montage moteur	: IM 1101	
Réglage de tension	: Unité RT à distance, ! 5%	
Norme	: CEI-34	

L'alternateur comportera un circuit d'amortissement pour fonctionner en parallèle avec d'autres alternateurs ou le secteur.

L'alternateur sera menu d'un système d'excitation à diodes tournantes. La puissance de commande de l'excitation est assurée par un régulateur automatique de tension.

Les soumissionnaires joindrent à leurs offres les caractéristiques détaillées de l'alternateur, système d'excitation, régulateur de tension et de toute autre composante no accessoire.

6) Systèmes auxiliaires :

Les soumissionnaires joindrent à leurs offres le descriptif technique détaillé des systèmes auxiliaires tel que :

- Système du combustible
- Système de lubrification
- Système d'air comprimé
- Système de refroidissement
- Système d'air de suralimentation ou de combustion
- Système de gaz d'échappement

7) **Equipement haute tension :**
Le soumissionnaire joindra à son offre les caractéristiques techniques des équipements haute tension et de l'appareillage à utiliser :
- Cellule 5,5 kV, arrivée alternateur
- Cellule point neutre
- Système de mise à la terre
- Système de verrouillage
- Protections
- Et tout autre équipement nécessaire à prévoir.

8) **Equipement basse tension :**
Le tableau général basse tension sera installé dans un local à la salle des moteurs. Ce tableau alimentera tous les auxiliaires (380 V CA- 110 V CC- 48 V CC- 24 V CC …)

Les panneaux de commande locale des groupes seront prévus dans le même local et comporteront les équipements de commande, synchronisation, régulation, etc.…

La commande à distance, la synchronisation, la mise en charge, les afficheurs, les enregistreurs et tout équipement similaire à prévoir seront dupliqués sur pupitre à la salle de contrôle.

9) **Etendue des travaux :**
Le présent marché consistant à fournir, installer et mettre en service une centrale à groupes électrogènes, clé en main. La société adjudicatrice aura à sa charge toutes fournitures et tous travaux nécessaires.

10) **Visite du site :**
Les sociétés soumissionnaires peuvent à effectuer une visite sur site afin de prendre connaissance des travaux à exécuter et des fournitures à prévoir, pour bien estimer leurs offres.

11) **Documents à joindre à l'offre :**
- Documentation technique détaillée des équipements proposés
- Plans et schémas de principe
- Planning détaillé de réalisation
- Bordereaux des prix.

<u>B/ GROUPES DE SECOURS 2x0,5 MW- 220 V- 50 Hz- 3Φ</u>

L'installation sera composée de deux groupes électrogènes d'une puissance totale de 1 MW.

Les conditions de site sont les mêmes. L'emplacement des 2 groupes est, à priori, dans le même bâtiment (salle des moteurs).

Les groupes électrogènes serviront de secours pour alimenter un tableau principal de distribution 220 V.

Les 2 groupes seront de type à temps de démarrage zéro, et seront à démarrage automatique ou manuel.

Les caractéristiques techniques principales sont :

Puissance nominale	: 525	kVA
Tension nominale	: 220	V triphasée
Fréquence	: 50	Hz
Classe d'échauffement	: F	
Classe d'isolement	: F	
Cos Φ	: 0,8	
Excitation	: Statique à diodes tournantes	
Réglage de tension	: Automatique	
Classe de protection	: IP 44	
Démarrage	: Batterie 24	V CC
Combustible	: Gazoil	

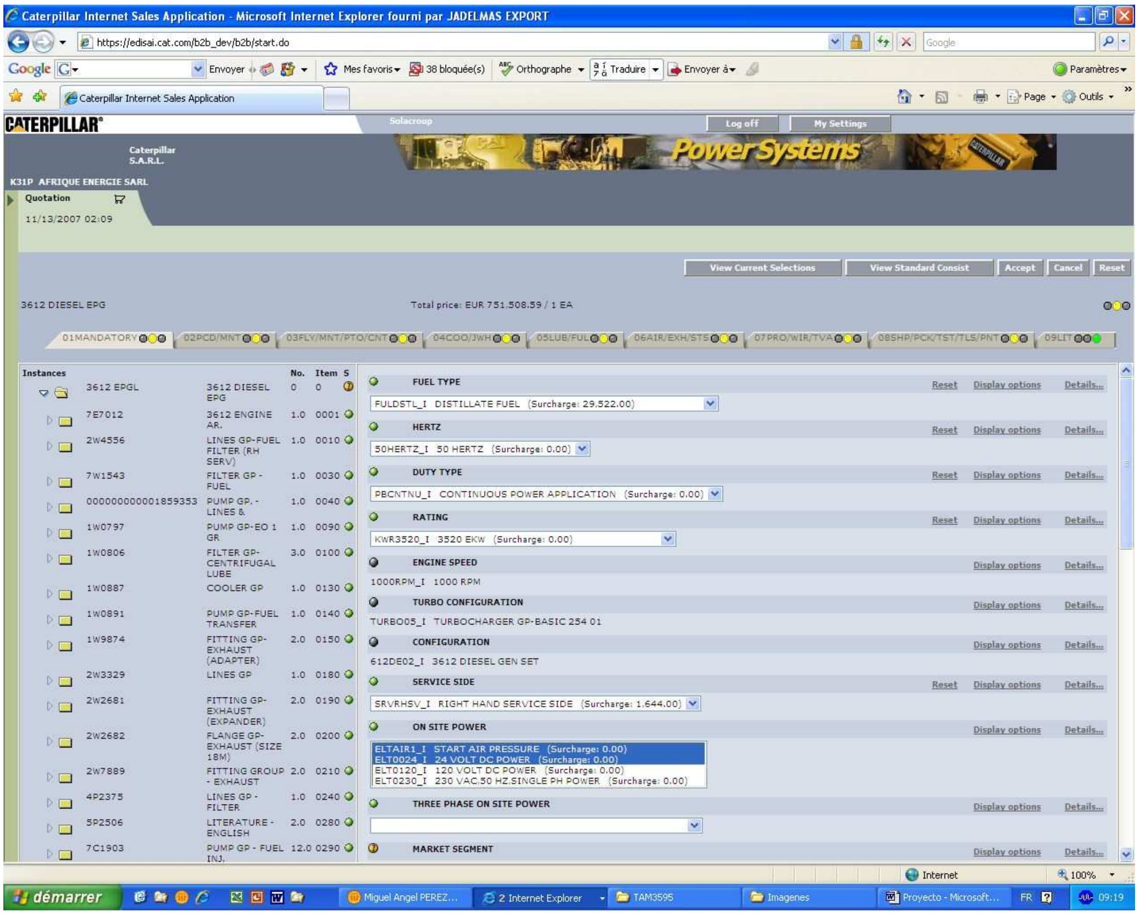
Les groupes électrogènes seront dotés d'une armoire chacun, dans laquelle il y aura le disjoncteur général sortie groupe avec les protections, l'alimentation des auxiliaires, les appareils de mesure…

Les sociétés soumissionnaires peuvent à effectuer une visite sur site afin de prendre connaissance des travaux à exécuter et des fournitures à prévoir, pour bien estimer leurs offres.

Les soumissionnaires doivent joindre à leurs offres :

- Documentation technique détaillée des équipements proposés
- Plans et schémas de principe
- Planning détaillé de réalisation
- Bordereaux des prix.

Anexo 2: Aplicación configuración grupo (CISA)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Power Systems
Log off
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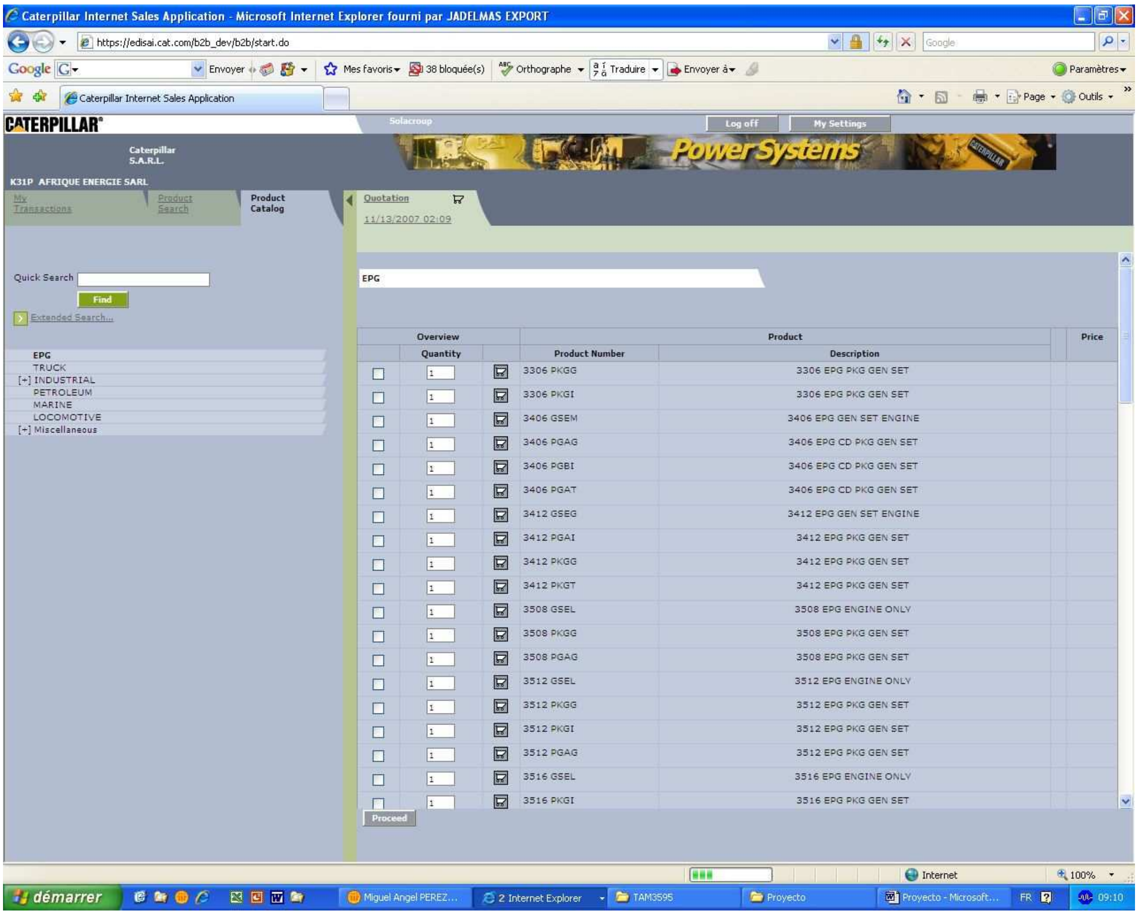
Caterpillar S.A.R.L.
K31P AFRIQUE ENERGIE SARL
Quotation
11/13/2007 02:09
View Current Selections
View Standard Consist
Accept
Cancel
Reset
3612 DIESEL EPG
Total price: EUR 751.508.59 / 1 EA
FUEL TYPE
FULDSTL_I DISTILLATE FUEL (Surcharge: 29.522.00)
HERTZ
50HERTZ_I 50 HERTZ (Surcharge: 0.00)
DUTY TYPE
PBCNTNU_I CONTINUOUS POWER APPLICATION (Surcharge: 0.00)
RATING
KWR3520_I 3520 EKW (Surcharge: 0.00)
ENGINE SPEED
1000RPM_I 1000 RPM
TURBO CONFIGURATION
TURBO05_I TURBOCHARGER GP-BASIC 254 01
CONFIGURATION
612DE02_I 3612 DIESEL GEN SET
SERVICE SIDE
SRVRHSV_I RIGHT HAND SERVICE SIDE (Surcharge: 1.644.00)
ON SITE POWER
ELTAIR1_I START AIR PRESSURE (Surcharge: 0.00)
ELT0024_I 24 VOLT DC POWER (Surcharge: 0.00)
ELT0120_I 120 VOLT DC POWER (Surcharge: 0.00)
ELT0230_I 230 VAC 50 HZ SINGLE PH POWER (Surcharge: 0.00)
THREE PHASE ON SITE POWER
MARKET SEGMENT
Reset
Display options
Details...
démarrer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CATERPILLAR
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K31P AFRIQUE ENERGIE SARL
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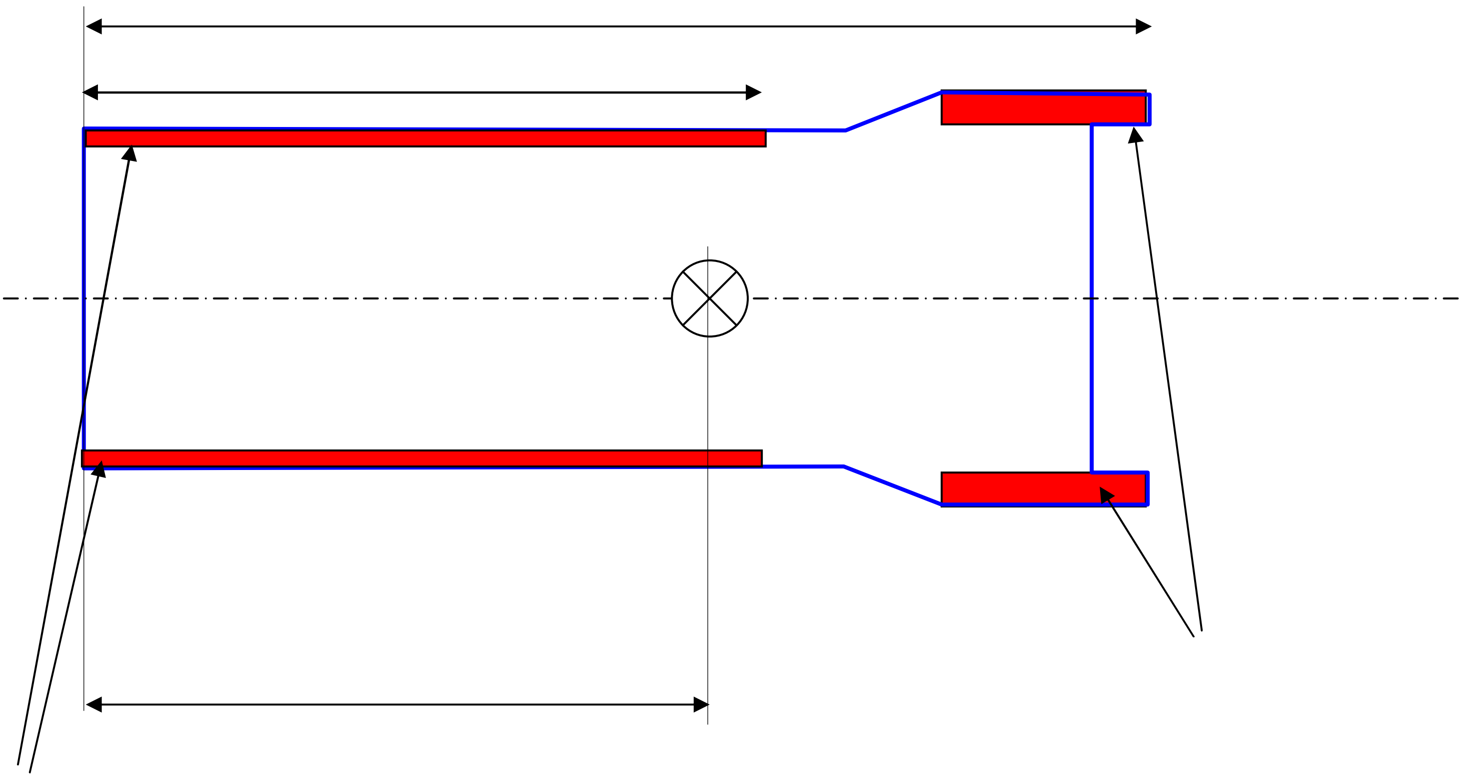
Power Systems
My Transactions
Product Search
Product Catalog
Quotation
11/13/2007 02:09
Quick Search
Find
Extended Search...
EPG
TRUCK
[+] INDUSTRIAL
PETROLEUM
MARINE
LOCOMOTIVE
[+] Miscellaneous
Overview
Quantity
Product
Product Number
Description
Price
3306 PKGG 3306 EPG PKG GEN SET
3306 PKGI 3306 EPG PKG GEN SET
3406 GSEM 3406 EPG GEN SET ENGINE
3406 PGAG 3406 EPG CD PKG GEN SET
3406 PGBI 3406 EPG CD PKG GEN SET
3406 PGAT 3406 EPG CD PKG GEN SET
3412 GSEG 3412 EPG GEN SET ENGINE
3412 PGAI 3412 EPG PKG GEN SET
3412 PKGG 3412 EPG PKG GEN SET
3412 PKGT 3412 EPG PKG GEN SET
3508 GSEL 3508 EPG ENGINE ONLY
3508 PKGG 3508 EPG PKG GEN SET
3508 PGAG 3508 EPG PKG GEN SET
3512 GSEL 3512 EPG ENGINE ONLY
3512 PKGG 3512 EPG PKG GEN SET
3512 PKGI 3512 EPG PKG GEN SET
3512 PGAG 3512 EPG PKG GEN SET
3516 GSEL 3516 EPG ENGINE ONLY
3516 PKGI 3516 EPG PKG GEN SET
Proceed
Internet
100%
démarrer
Proyecto
09:10

Anexo 3: Amortiguación de vibraciones

SCHEMA DE PRINCIPE DE REPARTITION DE CHARGE



Fréquence excitatrice :	25 Hz
Fréquence propre de l'ensemble suspendu :	9,5Hz
Déflexion sous charge :	3 à 4mm
Atténuation vibratoire (en solidien) :	83,50%

Anexo 4: Incotérminos

INTRODUCTION

1. PURPOSE AND SCOPE OF INCOTERMS

The purpose of Incoterms is to provide a set of international rules for the interpretation of the most commonly used trade terms in foreign trade. Thus, the uncertainties of different interpretations of such terms in different countries can be avoided or at least reduced to a considerable degree.

Frequently, parties to a contract are unaware of the different trading practices in their respective countries. This can give rise to misunderstandings, disputes and litigation with all the waste of time and money that this entails. In order to remedy these problems the International Chamber of Commerce first published in 1936 a set of international rules for the interpretation of trade terms. These rules were known as «Incoterms 1936». Amendments and additions were later made in 1953, 1967, 1976, 1980, 1990 and presently in 2000 in order to bring the rules in line with current international trade practices.

It should be stressed that the scope of Incoterms is limited to matters relating to the rights and obligations of the parties to the contract of sale with respect to the delivery of goods sold (in the sense of «tangibles », not including «intangibles» such as computer software).

It appears that two particular misconceptions about Incoterms are very common. First, Incoterms are frequently misunderstood as applying to the contract of carriage rather than to the contract of sale. Second, they are sometimes wrongly assumed to provide for all the duties which parties may wish to include in a contract of sale.

As has always been underlined by ICC, Incoterms deal only with the relation between sellers and buyers under the contract of sale, and, moreover, only do so in some very distinct respects.

While it is essential for exporters and importers to consider the very practical relationship between the various contracts needed to perform an international sales transaction - where not only the contract of sale is required, but also contracts of carriage, insurance and financing - Incoterms relate to only one of these contracts, namely the contract of sale.

Nevertheless, the parties' agreement to use a particular Incoterm would necessarily have implications for the other contracts.

To mention a few examples, a seller having agreed to a CFR - or CIF -contract cannot perform such a contract by any other mode of transport than carriage by sea, since under these terms he must present a bill of lading or other maritime document to the buyer which is simply not possible if other modes of transport are used. Furthermore, the document required under a documentary credit would necessarily depend upon the means of transport intended to be used.

Second, Incoterms deal with a number of identified obligations imposed on the parties - such as the seller's obligation to place the goods at the disposal of the buyer or hand them over for carriage or deliver them at destination - and with the distribution of risk between the parties in these cases.

Further, they deal with the obligations to clear the goods for export and import, the packing of the goods, the buyer's obligation to take delivery as well as the obligation to provide proof that the respective obligations have been duly fulfilled. Although Incoterms are extremely important for the implementation of the contract of sale, a great number of problems which may occur in such a contract are not dealt with at all, like transfer of ownership and other property rights, breaches of contract and the consequences following from such breaches as well as exemptions from liability in certain situations. It should be stressed that Incoterms are not intended to replace such contract terms that are needed for a complete contract of sale either by the incorporation of standard terms or by individually negotiated terms.

Generally, Incoterms do not deal with the consequences of breach of contract and any exemptions from liability owing to various impediments. These questions must be resolved by other stipulations in the contract of sale and the applicable law.

Incoterms have always been primarily intended for use where goods are sold for delivery across national boundaries: hence, international commercial terms. However, Incoterms are in practice at times also incorporated into contracts for the sale of goods within purely domestic markets. Where Incoterms are so used, the A2 and B2 clauses and any other stipulation of other articles dealing with export and import do, of course, become redundant.

2. WHY REVISIONS OF INCOTERMS?
The main reason for successive revisions of Incoterms has been the need to adapt them to contemporary commercial practice. Thus, in the 1980 revision the term Free Carrier (now FCA) was introduced in order to deal with the frequent case
where the reception point in maritime trade was no longer the traditional FOB-point (passing of the ship's rail) but rather a point
on land, prior to loading on board a vessel, where the goods were stowed into a container for subsequent transport by sea or
by different means of transport in combination (so-called combined or multimodal transport).
Further, in the 1990 revision of Incoterms, the clauses dealing with the seller's obligation to provide proof of delivery permitted
a replacement of paper documentation by EDI-messages provided the parties had agreed to communicate electronically.
Needless to say, efforts are constantly made to improve upon the at the seller's own premises (the «E»-term Ex works);
followed by the drafting and presentation of Incoterms in order to facilitate their practical implementation.
3. INCOTERMS 2000
During the process of revision, which has taken about two years, ICC has done its best to invite views and responses to successive drafts from a wide ranging spectrum of world traders, represented as these various sectors are on the national
committees through which ICC operates. Indeed, it has been gratifying to see that this revision process has attracted far more
reaction from users around the world than any of the previous revisions of Incoterms. The result of this dialogue is Incoterms
2000, a version which when compared with Incoterms 1990 may appear to have effected few changes. It is clear, however,
that Incoterms now enjoy world wide recognition and ICC has therefore decided to consolidate upon that recognition and avoid
change for its own sake. On the other hand, serious efforts have been made to ensure that the wording used in Incoterms
2000 clearly and accurately reflects trade practice. Moreover, substantive changes have been made in two areas:
• the customs clearance and payment of duty obligations under FAS and DEQ; and
• the loading and unloading obligations under FCA.
All changes, whether substantive or formal have been made on the basis of thorough research among users of Incoterms and
particular regard has been given to queries received since 1990 by the Panel of Incoterms Experts, set up as an additional

service to the users of Incoterms.
4. INCORPORATION OF INCOTERMS INTO THE CONTRACT OF SALE
In view of the changes made to Incoterms from time to time, it is important to ensure that where the parties intend to incorporate Incoterms into their contract of sale, an express reference is always made to the current version of Incoterms. This
may easily be overlooked when, for example, a reference has been made to an earlier version in standard contract forms or in
order forms used by merchants. A failure to refer to the current version may then result in disputes as to whether the parties
intended to incorporate that version or an earlier version as a part of their contract. Merchants wishing to use Incoterms 2000
should therefore clearly specify that their contract is governed by «Incoterms 2000».
5. THE STRUCTURE OF INCOTERMS
In 1990, for ease of understanding, the terms were grouped in four basically different categories; namely starting with the term
whereby the seller only makes the goods available to the buyer at the seller's own premises (the «E»-term Ex works); followed
by the second group whereby the seller is called upon to deliver the goods to a carrier appointed by the buyer (the «F»-terms
FCA, FAS and FOB); continuing with the «C»-terms where the seller has to contract for carriage, but without assuming the risk
of loss of or damage to the goods or additional costs due to events occurring after shipment and dispatch (CFR, CIF, CPT and
CIP); and, finally, the «D»-terms whereby the seller has to bear all costs and risks needed to bring the goods to the place of
destination (DAF, DES, DEQ, DDU and DDP). The following chart sets out this classification of the trade terms.
Further, under all terms, as in Incoterms 1990, the respective obligations of the parties have been grouped under 10 headings
where each heading on the seller's side «mirrors» the position of the buyer with respect to the same subject matter.
6. TERMINOLOGY

While drafting Incoterms 2000, considerable efforts have been made to achieve as much consistency as possible and desirable with respect to the various expressions used throughout the thirteen terms. Thus, the use of different expressions
intended to convey the same meaning has been avoided. Also, whenever possible, the same expressions as appear in the
1980 UN Convention on Contracts for the International Sale of Goods (CISG) have been used.

"shipper"

n some cases it has been necessary to use the same term to express two different meanings simply because there has been
no suitable alternative. Traders will be familiar with this difficulty both in the context of contracts of sale and also of contracts of

INCOTERMS 2000

Group E
Departure
EXW Ex Works
Group F
Main carriage unpaid
FCA Free Carrier (... named place)
FAS Free Alongside Ship (...named port of shipment)
FOB Free On Board (... named port of shipment)
Group C
Main carriage paid
CFR Cost and Freight (... named port of destination)
CIF Cost, Insurance and Freight (... named port of destination)
CPT Carriage Paid To (... named place of destination)
CIP Carriage and Insurance Paid To (... named place of destination)
Group D
Arrival
DAF Delivered At Frontier (... named place)
DES Delivered Ex Ship (... named port of destination)
DEQ Delivered Ex Quay (... named port of destination)
DDU Delivered Duty Unpaid (... named place of destination)
DDP Delivered Duty Paid (... named place of destination)

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carriage. Thus, for example, the term «shipper» signifies both the person handing over the goods for carriage and the person
who makes the contract with the carrier: however, these two «shippers» may be different persons, for example under a FOB
contract where the seller would hand over the goods for carriage and the buyer would make the contract with the carrier.

"delivery"

It is particularly important to note that the term «delivery» is used in two different senses in Incoterms. First, it is used to determine when the seller has fulfilled his delivery obligation which is specified in the A4 clauses throughout Incoterms. Second, the term «delivery» is also used in the context of the buyer's obligation to take or accept delivery of the goods, an
obligation which appears in the B4 clauses throughout Incoterms. Used in this second context, the word "delivery" means first
that the buyer "accepts" the very nature of the "C"-terms, namely that the seller fulfils his obligations upon the shipment of the
goods and, second that the buyer is obliged to receive the goods. This latter obligation is important so as to avoid unnecessary
charges for storage of the goods until they have been collected by the buyer. Thus, for example under CFR and CIF contracts,
the buyer is bound to accept delivery of the goods and to receive them from the carrier and if the buyer fails to do so, he may
become liable to pay damages to the seller who has made the contract of carriage with the carrier or, alternatively, the buyer
might have to pay demurrage charges resting upon the goods in order to obtain the carrier's release of the goods to him.
When it is said in this context that the buyer must "accept delivery", this does not mean that the buyer has accepted the goods
as conforming with the contract of sale, but only that he has accepted that the seller has performed his obligation to hand the
goods over for carriage in accordance with the contract of carriage which he has to make under the A3 a) clauses of the "C"-
terms. So, if the buyer upon receipt of the goods at destination were to find that the goods did not conform to the stipulations in
the contract of sale, he would be able to use any remedies which the contract of sale and the applicable law gave him against
the seller, matters which, as has already been mentioned, lie entirely outside the scope of Incoterms.

Where appropriate, Incoterms 2000, have used the expression «placing the goods at the disposal of» the buyer when the goods are made available to the buyer at a particular place. This expression is intended to bear the same meaning as that of the phrase "handing over the goods" used in the 1980 United Nations Convention on Contracts for the International Sale of Goods.

"usual"

The word "usual" appears in several terms, for example in EXW with respect to the time of delivery (A4) and in the "C"-terms with respect to the documents which the seller is obliged to provide and the contract of carriage which the seller must procure (A8, A3). It can, of course, be difficult to tell precisely what the word "usual" means, however, in many cases, it is possible to identify what persons in the trade usually do and this practice will then be the guiding light. In this sense, the word "usual" is rather more helpful than the word "reasonable", which requires an assessment not against the world of practice but against the more difficult principle of good faith and fair dealing. In some circumstances it may well be necessary to decide what is "reasonable". However, for the reasons given, in Incoterms the word "usual" has been generally preferred to the word "reasonable".

"charges"

With respect to the obligation to clear the goods for import it is important to determine what is meant by «charges» which must be paid upon import of the goods. In Incoterms 1990 the expression «official charges payable upon exportation and importation of the goods» was used in DDP A6. In Incoterms 2000 DDP A6 the word «official» has been deleted, the reason being that this word gave rise to some uncertainty when determining whether the charge was «official» or not. No change of substantive meaning was intended through this deletion. The «charges» which must be paid only concern such charges as are a necessary consequence of the import as such and which thus have to be paid according to the applicable import regulations.

Any additional charges levied by private parties in connection with the import are not to be included in these charges, such as charges for storage unrelated to the clearance obligation. However, the performance of that obligation may well result in some costs to customs brokers or freight forwarders if the party bearing the obligation does not do the work himself.

"ports", "places", "points" and "premises"

So far as concerns the place at which the goods are to be delivered, different expressions are used in Incoterms. In the terms intended to be used exclusively for carriage of goods by sea -such as FAS, FOB, CFR, CIF, DES and DEQ - the expressions «port of shipment» and «port of destination» have been used. In all other cases the word «place» has been used. In some cases, it has been deemed necessary also to indicate a «point» within the port or place as it may be important for the seller to know not only that the goods should be delivered in a particular area like a city but also where within that area the goods should be placed at the disposal of the buyer. Contracts of sale would frequently lack information in this respect and Incoterms therefore stipulate that if no specific point has been agreed within the named place, and if there are several points available, the seller may select the point which best suits his purpose (as an example see FCA A4). Where the delivery point is the seller's "place" the expression «the seller's premises» (FCA A4) has been used.

"ship" and "vessel"

In the terms intended to be used for carriage of goods by sea, the expressions «ship» and «vessel» are used as synonyms.

Needless to say, the term «ship» would have to be used when it is an ingredient in the trade term itself such as in «free alongside ship» (FAS) and «delivery ex ship» (DES). Also, in view of the traditional use of the expression «passed the ship's rail» in FOB, the word «ship» has had to be used in that connection.

"checking" and "inspection"

In the A9 and B9 clauses of Incoterms the headings «checking -packaging and marking» and «inspection of the goods» respectively have been used. Although the words «checking» and «inspection» are synonyms, it has been deemed appropriate to use the former word with respect to the seller's delivery obligation under A4 and to reserve the latter for the particular case when a «pre -shipment inspection» is performed, since such inspection normally is only required when the buyer or the authorities of the export or import country want to ensure that the goods conform with contractual or official stipulations before they are shipped.

7. THE SELLER'S DELIVERY OBLIGATIONS

Incoterms focus on the seller's delivery obligation. The precise distribution of functions and costs in connection with the seller's
delivery of the goods would normally not cause problems where the parties have a continuing commercial relationship. They
would then establish a practice between themselves («course of dealing») which they would follow in subsequent dealings in
the same manner as they have done earlier. However, if a new commercial relationship is established or if a contract is made
through the medium of brokers - as is common in the sale of commodities -, one would have to apply the stipulations of the
contract of sale and. whenever Incoterms 2000 have been incorporated into that contract, apply the division of functions, costs
and risks following therefrom.
It would, of course, have been desirable if Incoterms could specify in as detailed a manner as possible the duties of the parties

in connection with the delivery of the goods. Compared with Incoterms 1990, further efforts have been made in this respect in
some specified instances (see for example FCA A4). But it has not been possible to avoid reference to customs of the trade in
FAS and FOB A4 («in the manner customary at the port »), the reason being that particularly in commodity trade the exact
manner in which the goods are delivered for carriage in FAS and FOB contracts vary in the different sea ports.

8. PASSING OF RISKS AND COSTS RELATING TO THE GOODS

The risk of loss of or damage to the goods, as well as the obligation to bear the costs relating to the goods, passes from the
seller to the buyer when the seller has fulfilled his obligation to deliver the goods. Since the buyer should not be given the
possibility to delay the passing of the risk and costs, all terms stipulate that the passing of risk and costs may occur even
before delivery, if the buyer does not take delivery as agreed or fails to give such instructions (with respect to time for shipment
and/or place for delivery) as the seller may require in order to fulfil his obligation to deliver the goods. It is a requirement for
such premature passing of risk and costs that the goods have been identified as intended for the buyer or, as is stipulated in
the terms, set aside for him (appropriation).
This requirement is particularly important under EXW, since under all other terms the goods would normally have been
identified as intended for the buyer when measures have been taken for their shipment or dispatch («F» - and «C»-terms) or
their delivery at destination («D»-terms). In exceptional cases, however, the goods may have been sent from the seller in bulk
without identification of the quantity for each buyer and, if so, passing of risk and cost does not occur before the goods have
been appropriated as aforesaid (cf. also article 69.3 of the 1980 United Nations Convention on Contracts for the International
Sale of Goods).

9. THE TERMS

9.1 The"E"- term is the term in which the seller's obligation is at its minimum:
the seller has to do no more than place the goods at the disposal of the buyer at the agreed place - usually at the seller's own
premises. On the other hand, as a matter of practical reality, the seller would frequently assist the buyer in loading the goods
on the latter's collecting vehicle. Although EXW would better reflect this if the seller's obligations were to be extended so as to
include loading, it was thought desirable to retain the traditional principle of the seller's minimum obligation under EXW so that
it could be used for cases where the seller does not wish to assume any obligation whatsoever with respect to the loading of
the goods. If the buyer wants the seller to do more, this should be made clear in the contract of sale.

9.2 The"F" - terms require the seller to deliver the goods for carriage as instructed by the buyer. The point at which the parties
intend delivery to occur in the FCA term has caused difficulty because of the wide variety of circumstances which may
surround contracts covered by this term. Thus, the goods may be loaded on a collecting vehicle sent by the buyer to pick them
up at the seller's premises; alternatively, the goods may need to be unloaded from a vehicle sent by the seller to deliver the
goods at a terminal named by the buyer. Incoterms 2000 take account of these alternatives by stipulating that, when the place

named in the contract as the place of delivery is the seller's premises, delivery is complete when the goods are loaded on the buyer's collecting vehicle and, in other cases, delivery is complete when the goods are placed at the disposal of the buyer not unloaded from the seller's vehicle. The variations mentioned for different modes of transport in FCA A4 of Incoterms 1990 are not repeated in Incoterms 2000.

The delivery point under FOB, which is the same under CFR and CIF, has been left unchanged in Incoterms 2000 in spite of a considerable debate. Although the notion under FOB to deliver the goods «across the ship's rail» nowadays may seem inappropriate in many cases, it is nevertheless understood by merchants and applied in a manner which takes account of the goods and the available loading facilities. It was felt that a change of the FOB-point would create unnecessary confusion, particularly with respect to sale of commodities carried by sea typically under charter parties.

Unfortunately, the word «FOB» is used by some merchants merely to indicate any point of delivery-such as «FOB factory», «FOB plant», «FOB Ex seller's works» or other inland points -thereby neglecting what the abbreviation means: Free On Board.

It remains the case that such use of «FOB» tends to create confusion and should be avoided.

There is an important change of FAS relating to the obligation to clear the goods for export, since it appears to be the most common practice to put this duty on the seller rather than on the buyer. In order to ensure that this change is duly noted it has been marked with capital letters in the preamble of FAS.

9.3 The «C»-terms require the seller to contract for carriage on usual terms at his own expense. Therefore, a point up to which he would have to pay transport costs must necessarily be indicated after the respective «C»-term. Under the CIF and CIP terms the seller also has to take out insurance and bear the insurance cost. Since the point for the division of costs is fixed at a point in the country of destination, the «C»-terms are frequently mistakenly believed to be arrival contracts, in which the seller would bear all risks and costs until the goods have actually arrived at the agreed point. However, it must be stressed that the «C»-terms are of the same nature as the «F»-terms in that the seller fulfils the contract in the country of shipment or dispatch.

Thus, the contracts of sale under the «C»-terms, like the contracts under the «F»-terms, fall within the category of shipment contracts.

It is in the nature of shipment contracts that, while the seller is bound to pay the normal transport cost for the carriage of the goods by a usual route and in a customary manner to the agreed place, the risk of loss of or damage to the goods, as well as additional costs resulting from events occurring after the goods having been appropriately delivered for carriage, fall upon the buyer. Hence, the «C»-terms are distinguishable from all other terms in that they contain two «critical» points, one indicating the point to which the seller is bound to arrange and bear the costs of a contract of carriage and another one for the allocation of risk. For this reason, the greatest caution must be observed when adding obligations of the seller to the «C»-terms which seek to extend the seller's responsibility beyond the aforementioned «critical» point for the allocation of risk. It is of the very essence of the «C»-terms that the seller is relieved of any further risk and cost after he has duly fulfilled his contract by contracting for carriage and handing over the goods to the carrier and by providing for insurance under the CIF- and CIPterms.

The essential nature of the "C"-terms as shipment contracts is also illustrated by the common use of documentary credits as the preferred mode of payment used in such terms. Where it is agreed by the parties to the sale contract that the seller will be paid by presenting the agreed shipping documents to a bank under a documentary credit, it would be quite contrary to the central purpose of the documentary credit for the seller to bear further risks and costs after the moment when payment had been made under documentary credits or otherwise upon shipment and dispatch of the goods. Of course, the seller would have to bear the cost of the contract of carriage irrespective of whether freight is pre-paid upon shipment or is payable at destination (freight collect); however, additional costs which may result from events occurring subsequent to shipment and

dispatch are necessarily for the account of the buyer.
If the seller has to provide a contract of carriage which involves payment of duties, taxes and other charges, such costs will, of course, fall upon the seller to the extent that they are for his account under that contract. This is now explicitly set forth in the A6 clause of all "C"-terms.
If it is customary to procure several contracts of carriage involving transhipment of the goods at intermediate places in order to reach the agreed destination, the seller would have to pay all these costs, including any costs incurred when the goods are transhipped from one means of conveyance to the other. If, however, the carrier exercised his rights under a transhipment -or similar clause - in order to avoid unexpected hindrances (such as ice, congestion, labour disturbances, government orders, war or warlike operations) then any additional cost resulting therefrom would be for the account of the buyer, since the seller's obligation is limited to procuring the usual contract of carriage.
It happens quite often that the parties to the contract of sale wish to clarify the extent to which the seller should procure a contract of carriage including the costs of discharge. Since such costs are normally covered by the freight when the goods are carried by regular shipping lines, the contract of sale will frequently stipulate that the goods are to be so carried or at least that they are to be carried under «liner terms». In other cases, the word «landed» is added after CFR or CIF. However, it is advisable not to use abbreviations added to the «C»-terms unless, in the relevant trade, the meaning of the abbreviations is clearly understood and accepted by the contracting parties or under any applicable law or custom of the trade.
In particular, the seller should not - and indeed could not, without changing the very nature of the «C»-terms - undertake any obligation with respect to the arrival of the goods at destination, since the risk of any delay during the carriage is borne by the buyer. Thus, any obligation with respect to time must necessarily refer to the place of shipment or dispatch, for example, «shipment (dispatch) not later than...». An agreement for example, «CFR Hamburg not later than...» is really a misnomer and thus open to different possible interpretations. The parties could be taken to have meant either that the goods must actually arrive at Hamburg at the specified date, in which case the contract is not a shipment contract but an arrival contract or, alternatively, that the seller must ship the goods at such a time that they would normally arrive at Hamburg before the specified date unless the carriage would have been delayed because of unforeseen events.
It happens in commodity trades that goods are bought while they are at sea and that, in such cases, the word «afloat» is added after the trade term. Since the risk of loss of or damage to the goods would then, under the CFR- and CIF-terms, have passed from the seller to the buyer, difficulties of interpretation might arise. One possibility would be to maintain the ordinary meaning of the CFR- and CIF-terms with respect to the allocation of risk between seller and buyer, namely that risk passes on shipment: this would mean that the buyer might have to assume the consequences of events having already occurred at the time when the contract of sale enters into force. The other possibility would be to let the passing of the risk coincide with the time when the contract of sale is concluded. The former possibility might well be practical, since it is usually impossible to ascertain the condition of the goods while they are being carried. For this reason the 1980 United Nations Convention on Contracts for the International Sale of Goods article 68 stipulates that «if the circumstances so indicate, the risk is assumed by the buyer from the time the goods were handed over to the carrier who issued the documents embodying the contract of carriage». There is, however, an exception to this rule when «the seller knew or ought to have known that the goods had been lost or damaged and did not disclose this to the buyer». Thus, the interpretation of a CFR- or CIF-term with the addition of the word «afloat» will depend upon the law applicable to the contract of sale. The parties are advised to ascertain the applicable law and any solution which might follow therefrom. In case of doubt, the parties are advised to clarify the matter in their contract.
In practice, the parties frequently continue to use the traditional expression C&F (or Ñ and F, C+F). Nevertheless, in most cases it would appear that they regard these expressions as equivalent to CFR. In order to avoid difficulties of interpreting their contract the parties should use the correct Incoterm which is CFR, the only world-wide-accepted standard abbreviation for the

term «Cost and Freight (... named port of destination)».
CFR and CIF in A8 of Incoterms 1990 obliged the seller to provide a copy of the charterparty whenever his transport document (usually the bill of lading) contained a reference to the charterparty, for example, by the frequent notation «all other terms and conditions as per charterparty». Although, of course, a contracting party should always be able to ascertain all terms of his contract - preferably at the time of the conclusion of the contract - it appears that the practice to provide the charterparty as aforesaid has created problems particularly in connection with documentary credit transactions. The obligation of the seller under CFR and CIF to provide a copy of the charterparty together with other transport documents has been deleted in Incoterms 2000.
Although the A8 clauses of Incoterms seek to ensure that the seller provides the buyer with «proof of delivery», it should be stressed that the seller fulfils that requirement when he provides the «usual» proof. Under CPT and CIP it would be the «usual transport document» and under CFR and CIF a bill of lading or a sea waybill. The transport documents must be «clean», meaning that they must not contain clauses or notations expressly declaring a defective condition of the goods and/or the packaging. If such clauses or notations appear in the document, it is regarded as «unclean» and would then not be accepted by banks in documentary credit transactions. However, it should be noted that a transport document even without such clauses or notations would usually not provide the buyer with incontrovertible proof as against the carrier that the goods were shipped in conformity with the stipulations of the contract of sale. Usually, the carrier would, in standardized text on the front page of the transport document, refuse to accept responsibility for information with respect to the goods by indicating that the particulars inserted in the transport document constitute the shipper's declarations and therefore that the information is only «said to be» as inserted in the document. Under most applicable laws and principles, the carrier must at least use reasonable means of checking the correctness of the information and his failure to do so may make him liable to the consignee. However, in container trade, the carrier's means of checking the contents in the container would not exist unless he himself was responsible for stowing the container.
There are only two terms which deal with insurance, namely CIF and CIP. Under these terms the seller is obliged to procure insurance for the benefit of the buyer. In other cases it is for the parties themselves to decide whether and to what extent they want to cover themselves by insurance. Since the seller takes out insurance for the benefit of the buyer, he would not know the buyer's precise requirements. Under the Institute Cargo Clauses drafted by the Institute of London Underwriters, insurance is available in «minimum cover» under Clause C, «medium cover» under Clause Â and «most extended cover» under Clause A. Since in the sale of commodities under the CIF term the buyer may wish to sell the goods in transit to a subsequent buyer who in turn may wish to resell the goods again, it is impossible to know the insurance cover suitable to such subsequent buyers and, therefore, the minimum cover under CIF has traditionally been chosen with the possibility for the buyer to require the seller to take out additional insurance. Minimum cover is however unsuitable for sale of manufactured goods where the risk of theft, pilferage or improper handling or custody of the goods would require more than the cover available under Clause C.
Since CIP, as distinguished from CIF, would normally not be used for the sale of commodities, it would have been feasible to adopt the most extended cover under CIP rather than the minimum cover under CIF. But to vary the seller's insurance obligation under CIF and CIP would lead to confusion and both terms therefore limit the seller's insurance obligation to the minimum cover. It is particularly important for the CIP-buyer to observe this: should additional cover be required, he should

agree with the seller that the latter could take out additional insurance or, alternatively, arrange for extended insurance cover himself. There are also particular instances where the buyer may wish to obtain even more protection than is available under

Institute Clause A, for example insurance against war, riots, civil commotion, strikes or other labour disturbances. If he wishes the seller to arrange such insurance he must instruct him accordingly in which case the seller would have to provide such insurance if procurable.

9.4 The «D»-terms are different in nature from the «C»-terms, since the seller according to the «D»-terms is responsible for the arrival of the goods at the agreed place or point of destination at the border or within the country of import. The seller must bear all risks and costs in bringing the goods thereto. Hence, the «D»-terms signify arrival contracts, while the «C»-terms evidence departure (shipment) contracts.

Under the «D»-terms except DDP the seller does not have to deliver the goods cleared for import in the country of destination.

Traditionally, the seller had the obligation to clear the goods for import under DEQ, since the goods had to be landed on the quay and thus were brought into the country of import. But owing to changes in customs clearance procedures in most countries, it is now more appropriate that the party domiciled in the country concerned undertakes the clearance and pays the duties and other charges. Thus, a change in DEQ has been made for the same reason as the change in FAS previously mentioned. As in FAS, in DEQ the change has been marked with capital letters in the preamble.

It appears that in many countries trade terms not included in Incoterms are used particularly in railway traffic («franco border», «franco-frontiere», «Frei Grenze»). However, under such terms it is normally not intended that the seller should assume the risk of loss of or damage to goods during the transport up to the border. It would be preferable in these circumstances to use CPT indicating the border. If, on the other hand, the parties intend that the seller should bear the risk during the transport DAF indicating the border would be appropriate.

The DDU term was added in the 1990 version of Incoterms. The term fulfils an important function whenever the seller is prepared to deliver the goods in the country of destination without clearing the goods for import and paying the duty. In countries where import clearance may be difficult and time consuming, it may be risky for the seller to undertake an obligation to deliver the goods beyond the customs clearance point. Although, according to DDU B5 and B6, the buyer would have to bear the additional risks and costs which might follow from his failure to fulfil his obligations to clear the goods for import, the seller is advised not to use the DDU term in countries where difficulties might be expected in clearing the goods for import.

10. THE EXPRESSION «NO OBLIGATION»

As appears from the expressions «the seller must» and «the buyer must» Incoterms are only concerned with the obligations which the parties owe to each other. The words «no obligation» have therefore been inserted whenever one party does not owe an obligation to the other party. Thus, if for instance according to A3 of the respective term the seller has to arrange and pay for the contract of carriage we find the words «no obligation» under the heading «contract of carriage» in B3 a) setting forth the buyer's position. Again, where neither party owes the other an obligation, the words «no obligation» will appear with respect to both parties, for example, with respect to insurance.

In either case, it is important to point out that even though one party may be under "no obligation" towards the other to perform a certain task, this does not mean that it is not in his interest to perform that task. Thus, for example, just because a CFR buyer owes his seller no duty to make a contract of insurance under B4, it is clearly in his interest to make such a contract, the seller being under no such obligation to procure insurance cover under A4.

11. VARIANTS OF INCOTERMS

In practice, it frequently happens that the parties themselves by adding words to an Incoterm seek further precision than the term could offer. It should be underlined that Incoterms give no guidance whatsoever for such additions. Thus, if the parties cannot rely on a well-established custom of the trade for the interpretation of such additions they may encounter serious problems when no consistent understanding of the additions could be proven.

If for instance the common expressions «FOB stowed» or «EXW loaded» are used, it is impossible to establish aworld-wide understanding to the effect that the seller's obligations are extended not only with respect to the cost of actually loading the goods in the ship or on the vehicle respectively but also include the risk of fortuitous loss of or damage to the goods in the

process of stowage and loading. For these reasons, the parties are strongly advised to clarify whether they only mean that the
function or the cost of the stowage and loading operations should fall upon the seller or whether he should also bear the risk
until the stowage and loading has actually been completed. These are questions to which Incoterms do not provide an answer:
consequently, if the contract too fails expressly to describe the parties' intentions, the parties may be put to much unnecessary
trouble and cost.
Although Incoterms 2000 do not provide for many of these commonly used variants, the preambles to certain trade terms do
alert the parties to the need for special contractual terms if the parties wish to go beyond the stipulations of Incoterms.
In some cases sellers and buyers refer to commercial practice in liner and charter party trade. In these circumstances, it is
necessary to clearly distinguish between the obligations of the parties under the contract of carriage and their obligations to
each other under the contract of sale. Unfortunately, there are no authoritative definitions of expressions such as «liner terms»
and «terminal handling charges» (THC). Distribution of costs under such terms may differ in different places and change from
time to time. The parties are recommended to clarify in the contract of sale how such costs should be distributed between
themselves.
Expressions frequently used in charterparties, such as «FOB stowed», «FOB stowed and trimmed», are sometimes used in
contracts of sale in order to clarify to what extent the seller under FOB has to perform stowage and trimming of the goods
onboard the ship. Where such words are added, it is necessary to clarify in the contract of sale whether the added obligations
only relate to costs or to both costs and risks.
As has been said, every effort has been made to ensure that Incoterms reflect the most common commercial practice.
EXW the added obligation for the seller to load the goods on the buyer's collecting vehicle;
CIF/CIP the buyer's need for additional insurance;
DEQ the added obligation for the seller to pay for costs after discharge.

However in some cases - particularly where Incoterms 2000 differ from Incoterms 1990 - the parties may wish the trade terms
to operate differently. They are reminded of such options in the preamble of the terms signalled by the word «However».

12. CUSTOMS OF THE PORT OR OF A PARTICULAR TRADE

Since Incoterms provide a set of terms for use in different trades and regions it is impossible always to set forth the obligations
of the parties with precision. To some extent it is therefore necessary to refer to the custom of the port or of the particular trade
or to the practices which the parties themselves may have established in their previous dealings (cf. article 9 of the 1980
United Nations Convention on Contracts for the International Sale of Goods). It is of course desirable that sellers and buyers
keep themselves duly informed of such customs when they negotiate their contract and that, whenever uncertainty arises, they
clarify their legal position by appropriate clauses in their contract of sale. Such special provisions in the individual contract
would supersede or vary anything that is set forth as a rule of interpretation in the various Incoterms.

13. THE BUYER'S OPTIONS ASTOTHE PLACE OF SHIPMENT

In some situations, it may not be possible at the time when the contract of sale is entered into to decide precisely on the exact
point or even the place where the goods should be delivered by the seller for carriage. For instance reference might have been
made at this stage merely to a «range» or to a rather large place, for example, seaport, and it is then usually stipulated that the
buyer has the right or duty to name later on the more precise point within the range or the place. If the buyer has a duty to
name the precise point as aforesaid his failure to do so might result in liability to bear the risks and additional costs resulting
from such failure (B5/B7 of all terms). In addition, the buyer's failure to use his right to indicate the point may give the seller the
right to select the point which best suits his purpose (FCA A4).

14. CUSTOMS CLEARANCE

The term «customs clearance» has given rise to misunderstandings. Thus, whenever reference is made to an obligation of the

seller or the buyer to undertake obligations in connection with passing the goods through customs of the country of export or
import it is now made clear that this obligation does not only include the payment of duty and other charges but also the performance and payment of whatever administrative matters are connected with the passing of the goods through customs
and the information to the authorities in this connection. Further, it has - although quite wrongfully - been considered in some
quarters inappropriate to use terms dealing with the obligation to clear the goods through customs when, as in intra-European
Union trade or other free trade areas, there is no longer any obligation to pay duty and no restrictions relating to import or
export. In order to clarify the situation, the words «where applicable» have been added in the A2 and B2, A6 and B6 clauses of
the relevant Incoterms in order for them to be used without any ambiguity where no customs procedures are required.
It is normally desirable that customs clearance is arranged by the party domiciled in the country where such clearance should
take place or at least by somebody acting there on his behalf. Thus, the exporter should normally clear the goods for export,
while the importer should clear the goods for import.
Incoterms 1990 departed from this under the trade terms EXW and FAS (export clearance duty on the buyer) and DEQ (import
clearance duty on the seller) but in Incoterms 2000 FAS and DEQ place the duty of clearing the goods for export on the seller
and to clear them for import on the buyer respectively, while EXW -representing the seller's minimum obligation - has been left
unamended (export clearance duty on the buyer). Under DDP the seller specifically agrees to do what follows from the very
name of the term - Delivered Duty Paid - namely to clear the goods for import and pay any duty as a consequence thereof.

15. PACKAGING

In most cases, the parties would know beforehand which packaging is required for the safe carriage of the goods to destination. However, since the seller's obligation to pack the goods may well vary according to the type and duration of the
transport envisaged, it has been felt necessary to stipulate that the seller is obliged to pack the goods in such a manner as is
required for the transport, but only to the extent that the circumstances relating to the transport are made known to him before
the contract of sale is concluded (cf. articles 35.1. and 35.2.b. of the 1980 United Nations Convention on Contracts for the
International Sale of Goods where the goods, including packaging, must be «fit for any particular purpose expressly or impliedly made known to the seller at the time of the conclusion of the contract, except where the circumstances show that the
buyer did not rely, or that it was unreasonable for him to rely, on the seller's skill and judgement»).

16. INSPECTION OF GOODS

In many cases, the buyer may be well advised to arrange for inspection of the goods before or at the time they are handed
over by the seller for carriage (so-called pre -shipment inspection or PSI). Unless the contract stipulates otherwise, the buyer
would himself have to pay the cost for such inspection that is arranged in his own interest. However, if the inspection has been
made in order to enable the seller to comply with any mandatory rules applicable to the export of the goods in his own country,
the seller would have to pay for that inspection, unless the EXW term is used, in which case the costs of such inspection are
for the account of the buyer.

17. MODE OF TRANSPORT AND THE APPROPRIATE INCOTERM 2000

Any mode of transport

Group E EXW Ex Works (... named place)
Group F FCA Free Carrier (... named place)

18. THE RECOMMENDED USE

In some cases the preamble recommends the use or non-use of a particular term. This is particularly important with respect to
the choice between FCA and FOB. Regrettably, merchants continue to use FOB when it is totally out of place thereby causing
the seller to incur risks subsequent to the handing over of the goods to the carrier named by the buyer. FOB is only appropriate to use where the goods are intended to be delivered «across the ship's rail» or, in any event, to the ship and not

where the goods are handed over to the carrier for subsequent entry into the ship, for example stowed in containers or loaded
on lorries or wagons in so-called roll on - roll off traffic. Thus, a strong warning has been made in the preamble of FOB that the
term should not be used when the parties do not intend delivery across the ship's rail.
It happens that the parties by mistake use terms intended for carriage of goods by sea also when another mode of transport is
contemplated. This may put the seller in the unfortunate position that he cannot fulfil his obligation to tender the proper document to the buyer (for example a bill of lading, sea waybill or the electronic equivalent). The chart printed at paragraph 17
above makes clear which trade term in Incoterms 2000 it is appropriate to use for which mode of transport. Also, it is indicated
in the preamble of each term whether it can be used for all modes of transport or only for carriage of goods by sea.

19. THE BILL OF LADING AND ELECTRONIC COMMERCE

Traditionally, the on board bill of lading has been the only acceptable document to be presented by the seller under the CFR
and CIF terms. The bill of lading fulfils three important functions, namely:

• proof of delivery of the goods on board the vessel;
• evidence of the contract of carriage; and
• a means of transferring rights to the goods in transit to another party by the transfer of the paper document to him.

Transport documents other than the bill of lading would fulfil the two first-mentioned functions, but would not control the delivery of the goods at destination or enable a buyer to sell the goods in transit by surrendering the paper document to his
buyer. Instead, other transport documents would name the party entitled to receive the goods at destination. The fact that the
possession of the bill of lading is required in order to obtain the goods from the carrier at destination makes it particularly difficult to replace by electronic means of communication.
Further, it is customary to issue bills of lading in several originals but it is, of course, of vital importance for a buyer or a bank
acting upon his instructions in paying the seller to ensure that all originals are surrendered by the seller (so-called «full set»).
This is also a requirement under the ICC Rules for Documentary Credits (the so-called ICC Uniform Customs and Practice,
«UCP»;current version at date of publication of Incoterms 2000: ICC publication 500).
The transport document must evidence not only delivery of the goods to the carrier but also that the goods, as far as could be
ascertained by the carrier, were received in good order and condition. Any notation on the transport document which would
indicate that the goods had not been in such condition would make the document «unclean» and would thus make it unacceptable under the UCP.
In spite of the particular legal nature of the bill of lading it is expected that it will be replaced by electronic means in the near
future. The 1990 version of Incoterms had already taken this expected development into proper account. According to the A8
clauses, paper documents may be replaced by electronic messages provided the parties have agreed to communicate electronically. Such messages could be transmitted directly to the party concerned or through a third party providing addedvalue
services. One such service that can be usefully provided by a third party is registration of successive holders of a bill of lading. Systems providing such services, such as the so-called BOLERO service, may require further support by appropriate
legal norms and principles as evidenced by the CMI 1990 Rules for Electronic Bills of Lading and articles 16-17 of the 1996
UNCITRAL Model Law on Electronic Commerce.

20. NON-NEGOTIABLE TRANSPORT DOCUMENTS INSTEAD OF BILLS OF LADING

In recent years, a considerable simplification of documentary practices has been achieved. Bills of lading are frequently
Group C CPT Carriage Paid To (... named place of destination)
CIP Carriage and Insurance Paid To (... named place of destination)
Group D DAF Delivered At Frontier (... named place)
DDU Delivered Duty Unpaid (... named place of destination)
DDP Delivered Duty Paid (... named place of destination)
Maritime and inland waterway transport only
Group F FAS Free Alongside Ship (... named port of shipment)
FOB Free On Board (... named port of shipment)
Group C CFR Cost and Freight (... named port of destination)
CIF Cost, Insurance and Freight (... named port of destination)
Group D DES DES Delivered Ex Ship (... named port of destination)
DEQ Delivered Ex Quay (... named port of destination)

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replaced by non-negotiable documents similar to those which are used for other modes of transport than carriage by sea.
These documents are called «sea waybills», «liner waybills», «freight receipts», or variants of such expressions. Nonnegotiable
documents are quite satisfactory to use except where the buyer wishes to sell the goods in transit by surrendering a paper document to the new buyer. In order to make this possible, the obligation of the seller to provide a bill of lading under
CFR and CIF must necessarily be retained. However, when the contracting parties know that the buyer does not contemplate
selling the goods in transit, they may specifically agree to relieve the seller from the obligation to provide a bill of lading, or,
alternatively, they may use CPT and CIP where there is no requirement to provide a bill of lading.

21. THE RIGHT TO GIVE INSTRUCTIONS TO THE CARRIER

A buyer paying for the goods under a «C»-term should ensure that the seller upon payment is prevented from disposing of the
goods by giving new instructions to the carrier. Some transport documents used for particular modes of transport (air, road or
rail) offer the contracting parties a possibility to bar the seller from giving such new instructions to the carrier by providing the
buyer with a particular original or duplicate of the waybill. However, the documents used instead of bills of lading for maritime
carriage do not normally contain such a barring function. The Comite Maritime International has remedied this shortcoming of
the above-mentioned documents by introducing the 1990 «Uniform Rules for Sea Waybills» enabling the parties to insert a
«no-disposal» clause whereby the seller surrenders the right to dispose of the goods by instructions to the carrier to deliver the
goods to somebody else or at another place than stipulated in the waybill.

22. ICC ARBITRATION

Contracting parties who wish to have the possibility of resorting to ICC Arbitration in the event of a dispute with their contracting partner should specifically and clearly agree upon ICC Arbitration in their contract or, in the event that no single
contractual document exists, in the exchange of correspondence which constitutes the agreement between them. The fact of
incorporating one or more Incoterms in a contract or the related correspondence does NOT by itself constitute an agreement
to have resort to ICC Arbitration.
The following standard arbitration clause is recommended by ICC: «All disputes arising out of or in connection with the present
contract shall be finally settled under the Rules of Arbitration of the International Chamber of Commerce by one or more arbitrators appointed in accordance with the said Rules.»

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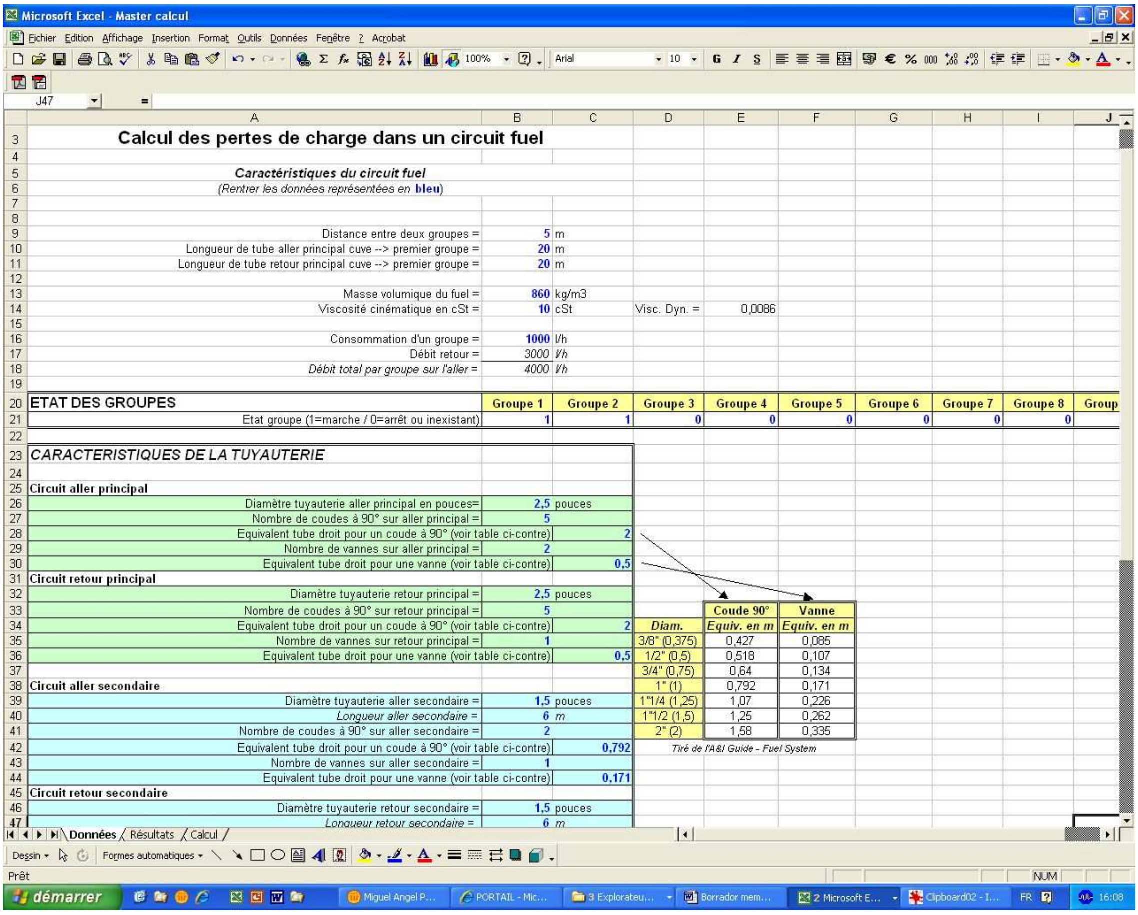
Anexo 5: Cálculo circuito combustible



Calcul des pertes de charge dans un circuit fuel

Caractéristiques du circuit fuel
(Rentrer les données représentées en bleu)

Distance entre deux groupes =	5	m		
Longueur de tube aller principal cuve --> premier groupe =	20	m		
Longueur de tube retour principal cuve --> premier groupe =	20	m		
Masse volumique du fuel =	860	kg/m3		
Viscosité cinématique en cSt =	10	cSt	Visc. Dyn. =	0,0086
Consommation d'un groupe =	1000	l/h		
Débit retour =	3000	l/h		
Débit total par groupe sur l'aller =	4000	l/h		

ETAT DES GROUPES	Groupe 1	Groupe 2	Groupe 3	Groupe 4	Groupe 5	Groupe 6	Groupe 7	Groupe 8	Group
Etat groupe (1=marche / 0=arrêt ou inexistant)	1	1	0	0	0	0	0	0	

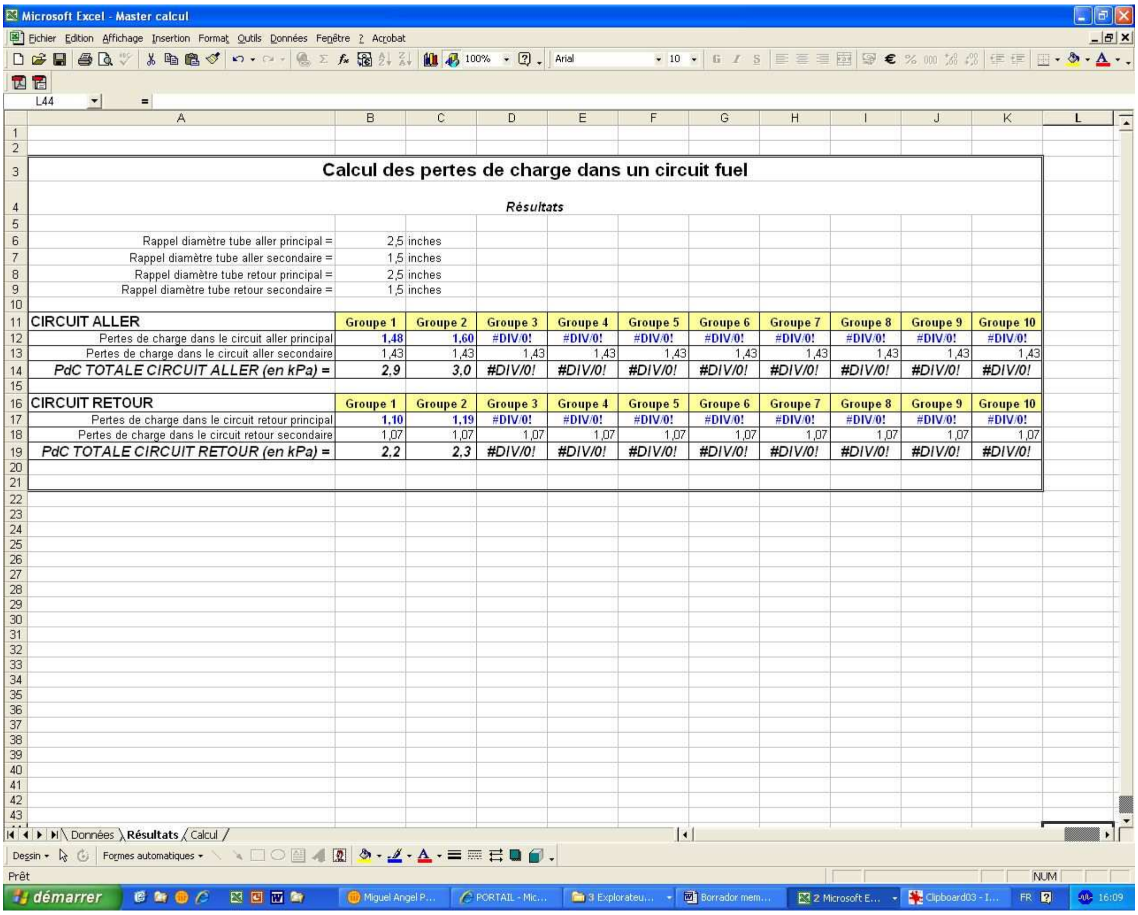
CARACTERISTIQUES DE LA TUYAUTERIE

Circuit aller principal		
Diamètre tuyauterie aller principal en pouces=	2,5	pouces
Nombre de coudes à 90° sur aller principal =	5	
Equivalent tube droit pour un coude à 90° (voir table ci-contre)		2
Nombre de vannes sur aller principal =	2	
Equivalent tube droit pour une vanne (voir table ci-contre)		0,5
Circuit retour principal		
Diamètre tuyauterie retour principal =	2,5	pouces
Nombre de coudes à 90° sur retour principal =	5	
Equivalent tube droit pour un coude à 90° (voir table ci-contre)		2
Nombre de vannes sur retour principal =	1	
Equivalent tube droit pour une vanne (voir table ci-contre)		0,5
Circuit aller secondaire		
Diamètre tuyauterie aller secondaire =	1,5	pouces
Longueur aller secondaire =	6	m
Nombre de coudes à 90° sur aller secondaire =	2	
Equivalent tube droit pour un coude à 90° (voir table ci-contre)		0,792
Nombre de vannes sur aller secondaire =	1	
Equivalent tube droit pour une vanne (voir table ci-contre)		0,171
Circuit retour secondaire		
Diamètre tuyauterie retour secondaire =	1,5	pouces
Longueur retour secondaire =	6	m

	Coude 90°	Vanne
Diam.	*Equiv. en m*	*Equiv. en m*
3/8" (0,375)	0,427	0,085
1/2" (0,5)	0,518	0,107
3/4" (0,75)	0,64	0,134
1" (1)	0,792	0,171
1"1/4 (1,25)	1,07	0,226
1"1/2 (1,5)	1,25	0,262
2" (2)	1,58	0,335

Tiré de l'A&I Guide - Fuel System

Données / Résultats / Calcul



Calcul des pertes de charge dans un circuit fuel

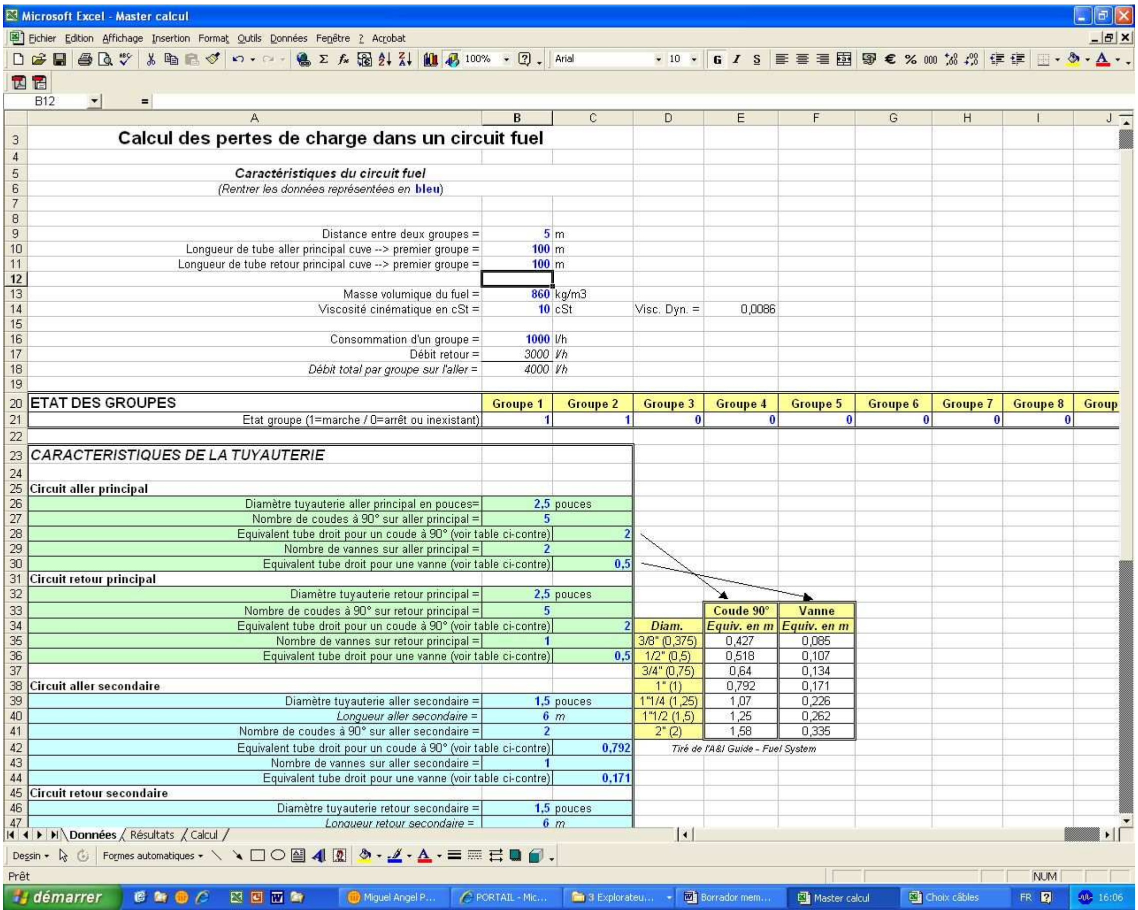
Résultats

Rappel diamètre tube aller principal =	2,5	inches
Rappel diamètre tube aller secondaire =	1,5	inches
Rappel diamètre tube retour principal =	2,5	inches
Rappel diamètre tube retour secondaire =	1,5	inches

CIRCUIT ALLER	Groupe 1	Groupe 2	Groupe 3	Groupe 4	Groupe 5	Groupe 6	Groupe 7	Groupe 8	Groupe 9	Groupe 10
Pertes de charge dans le circuit aller principal	1,48	1,60	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Pertes de charge dans le circuit aller secondaire	1,43	1,43	1,43	1,43	1,43	1,43	1,43	1,43	1,43	1,43
PdC TOTALE CIRCUIT ALLER (en kPa) =	*2,9*	*3,0*	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!

CIRCUIT RETOUR	Groupe 1	Groupe 2	Groupe 3	Groupe 4	Groupe 5	Groupe 6	Groupe 7	Groupe 8	Groupe 9	Groupe 10
Pertes de charge dans le circuit retour principal	1,10	1,19	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Pertes de charge dans le circuit retour secondaire	1,07	1,07	1,07	1,07	1,07	1,07	1,07	1,07	1,07	1,07
PdC TOTALE CIRCUIT RETOUR (en kPa) =	*2,2*	*2,3*	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!

Données / Résultats / Calcul



Calcul des pertes de charge dans un circuit fuel

Caractéristiques du circuit fuel

(Rentrer les données représentées en **bleu***)*

Distance entre deux groupes =	5	m
Longueur de tube aller principal cuve --> premier groupe =	100	m
Longueur de tube retour principal cuve --> premier groupe =	100	m
Masse volumique du fuel =	860	kg/m3
Viscosité cinématique en cSt =	10	cSt
Visc. Dyn. =	0,0086	
Consommation d'un groupe =	1000	l/h
Débit retour =	*3000*	*l/h*
Débit total par groupe sur l'aller =	*4000*	*l/h*

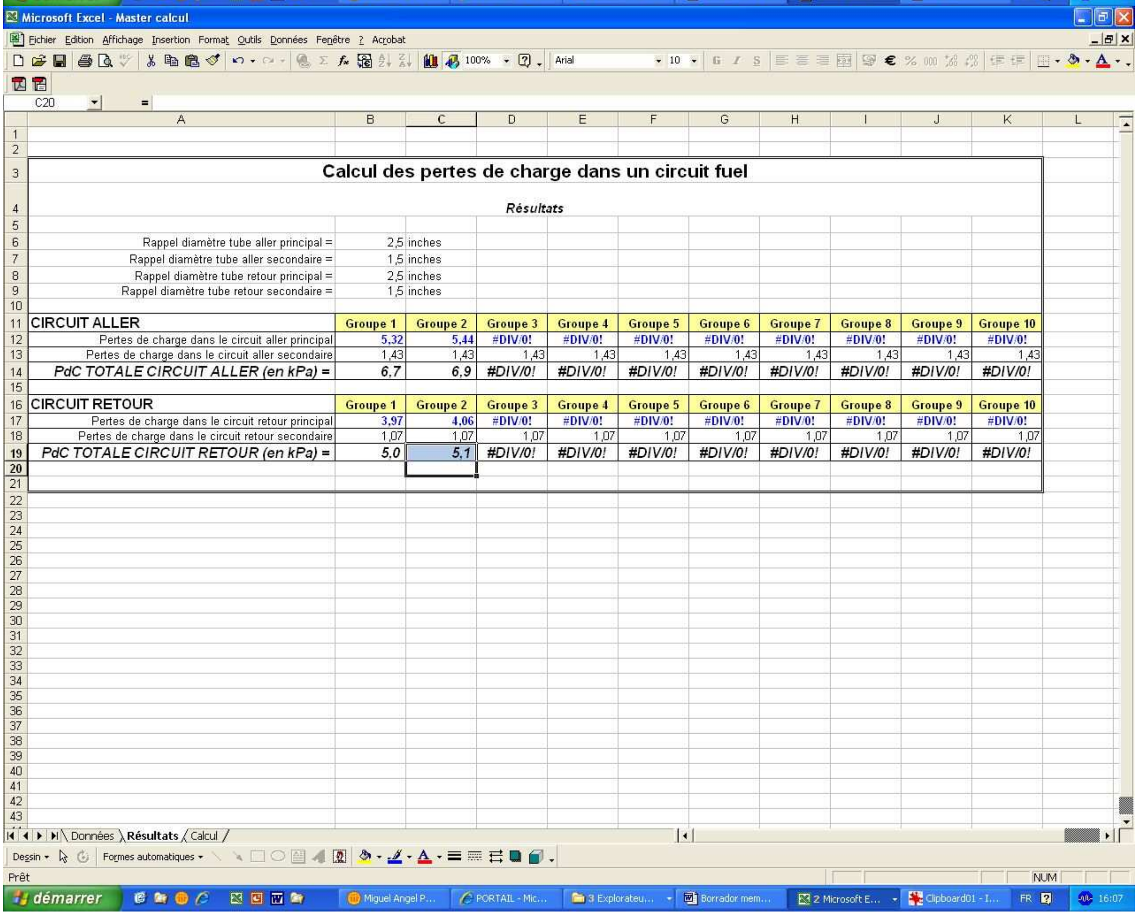
ETAT DES GROUPES	Groupe 1	Groupe 2	Groupe 3	Groupe 4	Groupe 5	Groupe 6	Groupe 7	Groupe 8	Group
Etat groupe (1=marche / 0=arrêt ou inexistant)	1	1	0	0	0	0	0	0	

CARACTERISTIQUES DE LA TUYAUTERIE

Circuit aller principal		
Diamètre tuyauterie aller principal en pouces=	2,5	pouces
Nombre de coudes à 90° sur aller principal =	5	
Equivalent tube droit pour un coude à 90° (voir table ci-contre)		2
Nombre de vannes sur aller principal =	2	
Equivalent tube droit pour une vanne (voir table ci-contre)		0,5
Circuit retour principal		
Diamètre tuyauterie retour principal =	2,5	pouces
Nombre de coudes à 90° sur retour principal =	5	
Equivalent tube droit pour un coude à 90° (voir table ci-contre)		2
Nombre de vannes sur retour principal =	1	
Equivalent tube droit pour une vanne (voir table ci-contre)		0,5
Circuit aller secondaire		
Diamètre tuyauterie aller secondaire =	1,5	pouces
Longueur aller secondaire =	6	*m*
Nombre de coudes à 90° sur aller secondaire =	2	
Equivalent tube droit pour un coude à 90° (voir table ci-contre)		0,792
Nombre de vannes sur aller secondaire =	1	
Equivalent tube droit pour une vanne (voir table ci-contre)		0,171
Circuit retour secondaire		
Diamètre tuyauterie retour secondaire =	1,5	pouces
Longueur retour secondaire =	6	*m*

	Coude 90°	Vanne
Diam.	*Equiv. en m*	*Equiv. en m*
3/8" (0,375)	0,427	0,085
1/2" (0,5)	0,518	0,107
3/4" (0,75)	0,64	0,134
1" (1)	0,792	0,171
1"1/4 (1,25)	1,07	0,226
1"1/2 (1,5)	1,25	0,262
2" (2)	1,58	0,335

Tiré de l'A&I Guide - Fuel System



Calcul des pertes de charge dans un circuit fuel

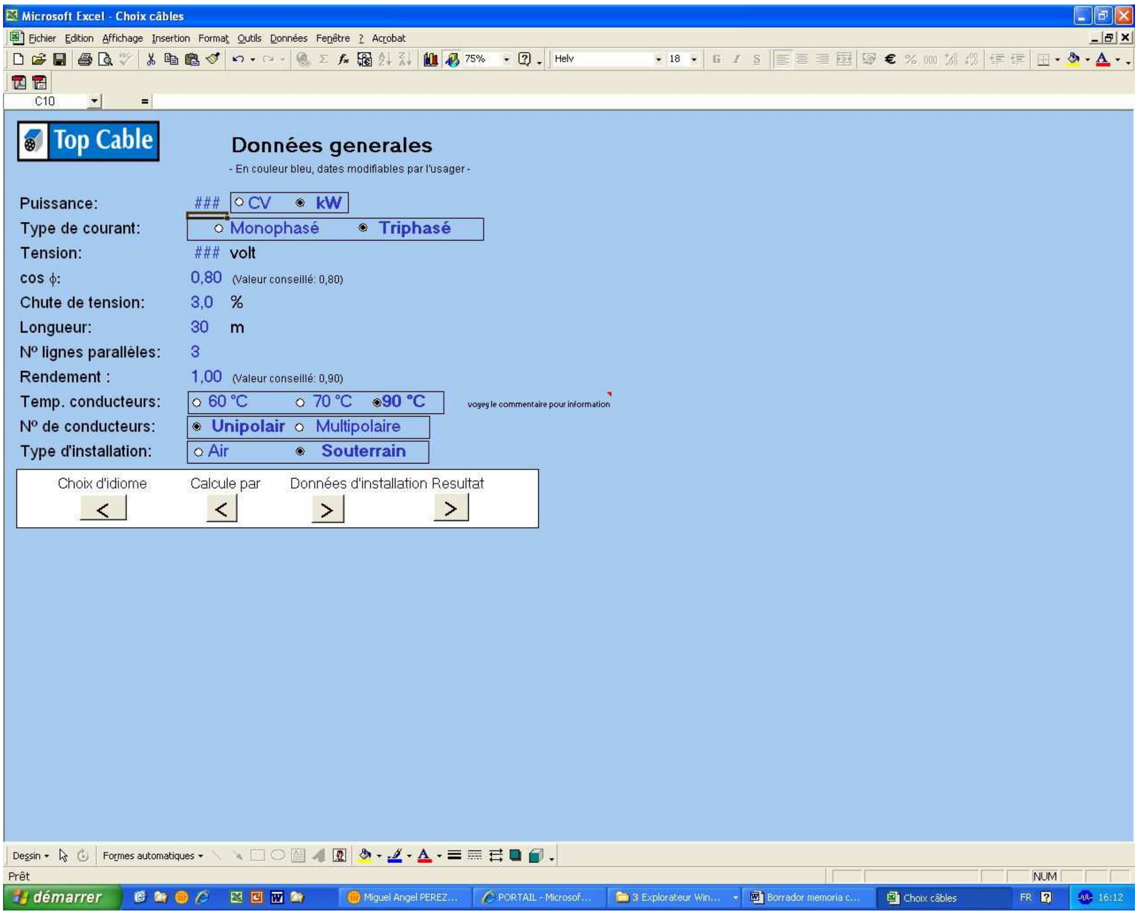
Résultats

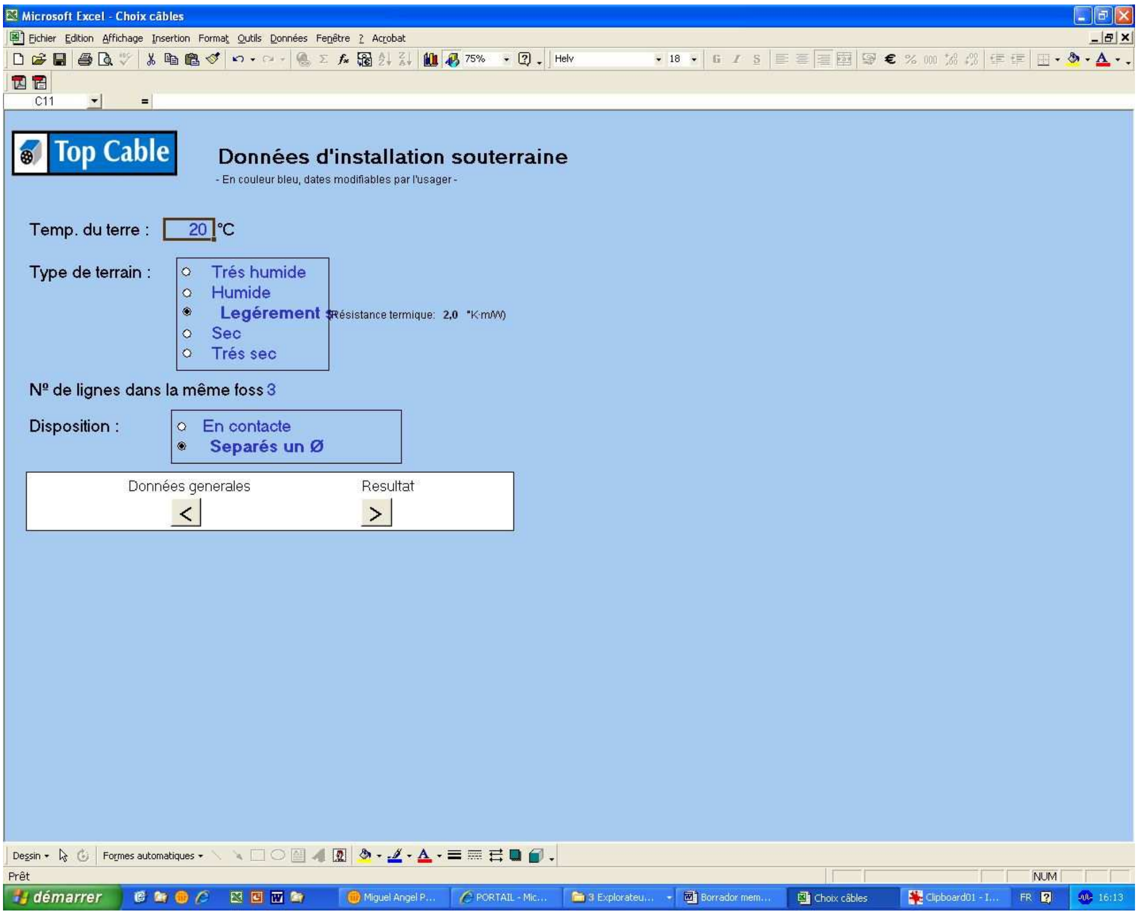
Rappel diamètre tube aller principal =	2,5	inches
Rappel diamètre tube aller secondaire =	1,5	inches
Rappel diamètre tube retour principal =	2,5	inches
Rappel diamètre tube retour secondaire =	1,5	inches

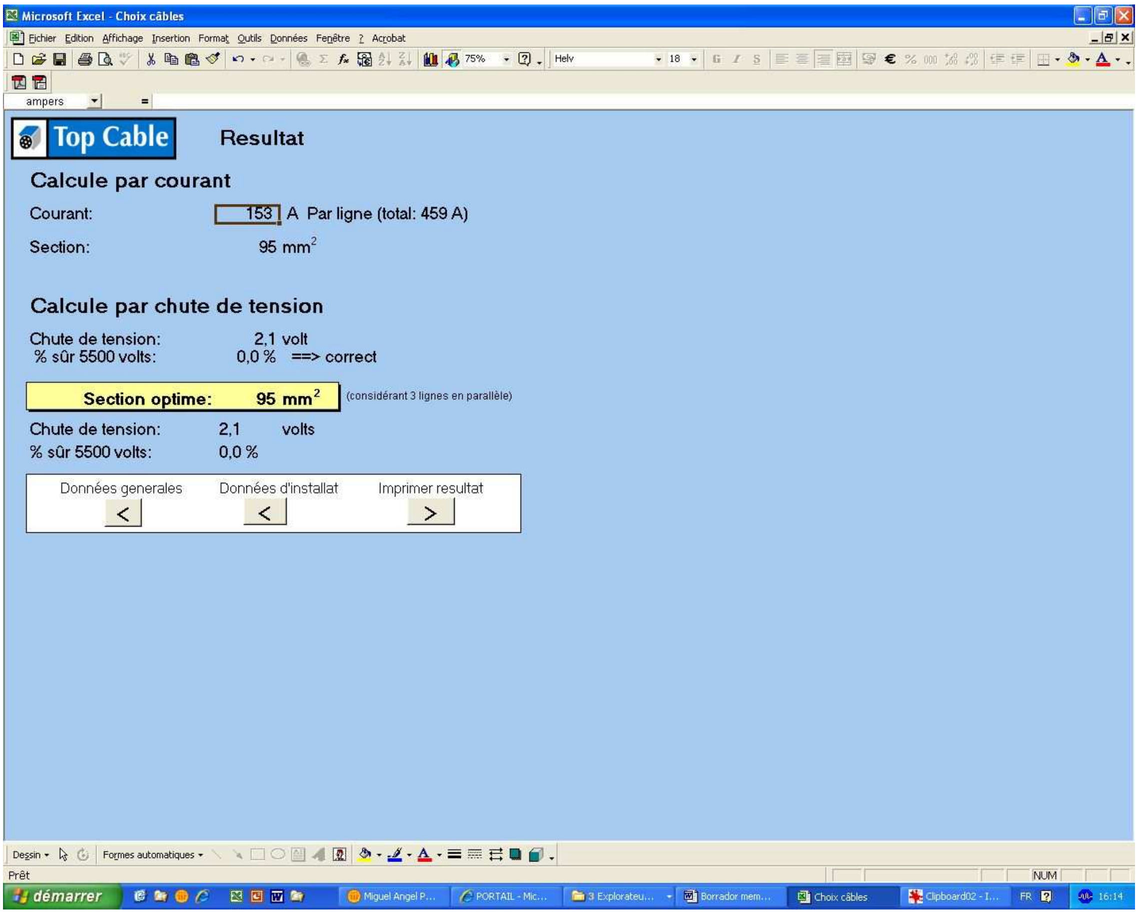
CIRCUIT ALLER	Groupe 1	Groupe 2	Groupe 3	Groupe 4	Groupe 5	Groupe 6	Groupe 7	Groupe 8	Groupe 9	Groupe 10
Pertes de charge dans le circuit aller principal	5,32	5,44	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Pertes de charge dans le circuit aller secondaire	1,43	1,43	1,43	1,43	1,43	1,43	1,43	1,43	1,43	1,43
PdC TOTALE CIRCUIT ALLER (en kPa) =	6,7	6,9	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!

CIRCUIT RETOUR	Groupe 1	Groupe 2	Groupe 3	Groupe 4	Groupe 5	Groupe 6	Groupe 7	Groupe 8	Groupe 9	Groupe 10
Pertes de charge dans le circuit retour principal	3,97	4,06	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Pertes de charge dans le circuit retour secondaire	1,07	1,07	1,07	1,07	1,07	1,07	1,07	1,07	1,07	1,07
PdC TOTALE CIRCUIT RETOUR (en kPa) =	5,0	5,1	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!

Anexo 6: Cálculo instalación eléctrica potencia


Microsoft Excel - Choix câbles
Top Cable
Données generales
- En couleur bleu, dates modifiables par l'usager -
Puissance: ### CV kW
Type de courant: Monophasé Triphasé
Tension: ### volt
cos ϕ: 0,80 (Valeur conseillé: 0,80)
Chute de tension: 3,0 %
Longueur: 30 m
Nº lignes parallèles: 3
Rendement : 1,00 (Valeur conseillé: 0,90)
Temp. conducteurs: 60 °C 70 °C 90 °C
voyez le commentaire pour information
Nº de conducteurs: Unipolair Multipolaire
Type d'installation: Air Souterrain
Choix d'idiome
Calcule par
Données d'installation
Resultat
démarrer


Microsoft Excel - Choix câbles
Top Cable
Données d'installation souterraine
- En couleur bleu, dates modifiables par l'usager -
Temp. du terre : 20 °C
Type de terrain :
Trés humide
Humide
Legérement
Résistance termique: 2,0 °K·m/W
Sec
Trés sec
Nº de lignes dans la même foss 3
Disposition :
En contacte
Separés un Ø
Données generales
Resultat
démarrer


Microsoft Excel - Choix câbles
Top Cable
Resultat
Calcule par courant
Courant: 153 A Par ligne (total: 459 A)
Section: 95 mm2
Calcule par chute de tension
Chute de tension: 2,1 volt
% sûr 5500 volts: 0,0 % ==> correct
Section optime: 95 mm2
(considérant 3 lignes en parallèle)
Chute de tension: 2,1 volts
% sûr 5500 volts: 0,0 %
Données generales
Données d'installat
Imprimer resultat

Anexo 7: Diseño soportes silenciadores

Africa Power Systems CAT

Africa Power Systems S.A.S
17 rue Vauban
33075 Bordeaux Cedex France
Tél. : +33 (0)5.56.00.53.12
Fax : +33 (0)5.56.00.53.15

CUSTOMER / CLIENT	**SAMIR**
PROJECT Name - N°	**Samir refinery Mohamedia - Morocco**
DOCUMENT N°	**98DA 3& 4 – chem/echpt**
TITLE / TITRE	**ETUDE DE CHARPENTE SILENCIEUX**
DATE	**13/08/03**

ETUDE DE CHARPENTE / SUPPORT ECHAPPEMENT

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HYPOTHESE DE CALCULS

1/ Charger paramètres

Poids propre : Silencieux
+ Déflecteur
+ Tuyauterie
1200 kg / par ligne d'échappement

2/ Neige : négligeable

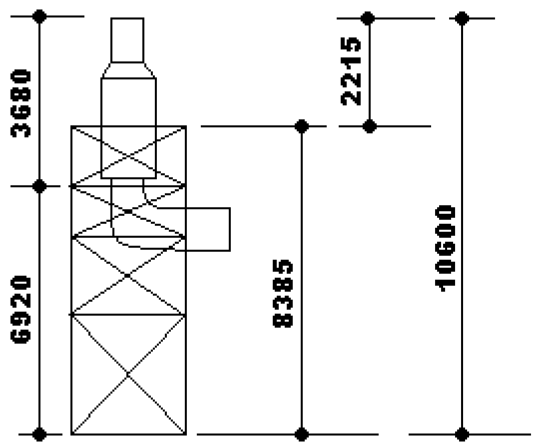
3/ Vent : similaire à celui de bordeaux _ site exposé _ K=13
78 / 137 km/hr

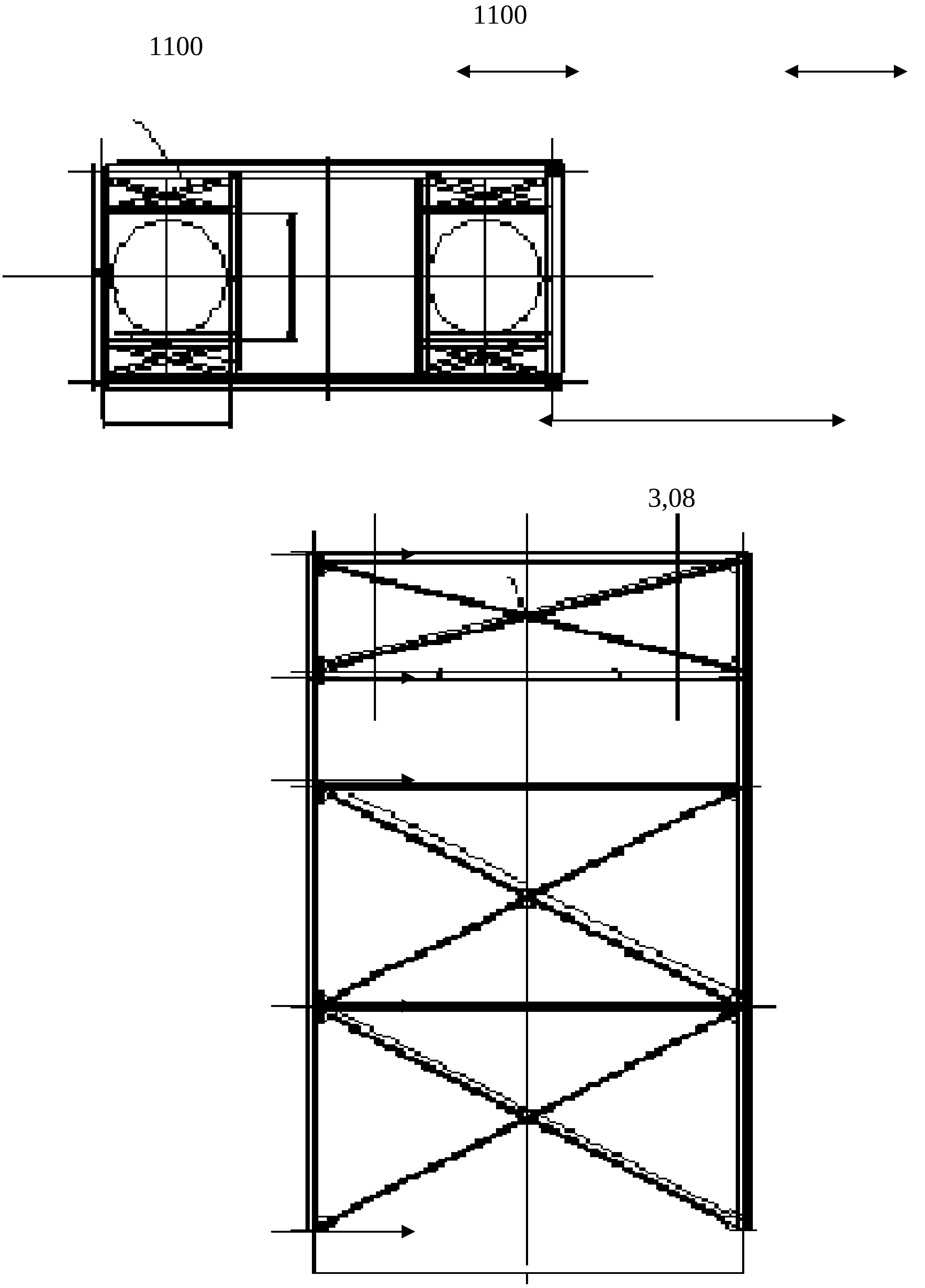
4/ Séisme (suivant PS 69)
Zone 3 – Forte séismicité α=1,5

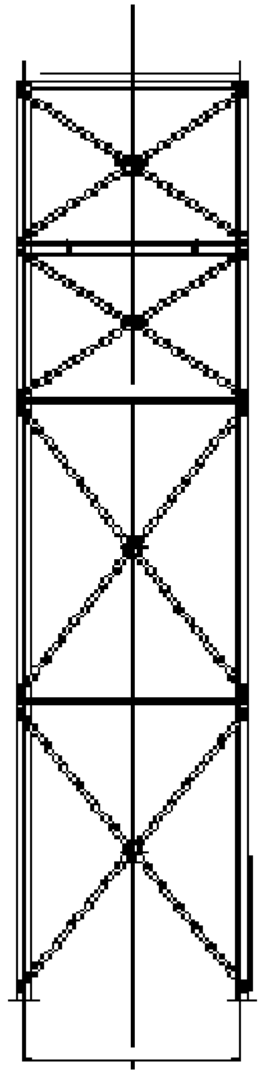
DIMENTION

(Pour élévation de l'effort seulement)

suivre la côte




1100
1100
3,08



ACTION DU VENT

1/ Sur la partie d'échappement au dessus de la structure

$d\sqrt{q} = 1{,}10\sqrt{78} = 9{,}7 > 1{,}5$ Ct=0,55
Hauteur au dessus de la structure est d'environ 2215 mm
F = 78 x 2,215 x 1,10 x 0,55 = 104 kg / silencieux

2/ Sur la structure et la partie d'échappement à l'intérieur de la structure

Hypothèse : le pylône est supposé plein à 50%

2.1/ Vent perpendiculaire à grande façade

F2,85 = 78 x 1,30 x 0,85 x 2,85 x 2,16 x 0,5 =264 kg
F5,70 = 78 x 1,30 x 0,85 x 2,035 x 2,16 x 0,5 = 189 kg
F6,22 = 78 x 1,30 x 0,85 x 1,34 x 2,16 x 0,5 = 124 kg
F8,385 = 78 x 1,30 x 0,85 x 0,73 x 2,16 x 0,5 = 68 kg

2.2/ Vent perpendiculaire à petite façade

F2,85 = 78 x 1,30 x 0,85 x 2,85 x 1 x 0,5 =123 kg
F5,70 = 78 x 1,30 x 0,85 x 2,035 x 1 x 0,5 = 88 kg
F6,22 = 78 x 1,30 x 0,85 x 1,34 x 1 x 0,5 = 68 kg
F8,385 = 78 x 1,30 x 0,85 x 0,73 x 1 x 0,5 = 31 kg

SEISME

Intensité de la force horizontale

T🙚 = 🙚 x 🙜 x 🙞 x 🙠

Coefficient d'intensité 🙚 🙚 =1,5 (forte séismicité)

Coefficient de réponse 🙜 🙜MAX = 0,2 (Max Amortissement faible)

Coefficient de distribution 🙞 🙞 = 1 1 étage

Coefficient de fondation 🙠 max 🙠 =1,30 (limon et vase gorgé d'eau)

Th = 1,5 x 0,2 x 1 x 1,30 = 0,39

Action horizontale par file St x / St y

Fx = Fy = 1200 x 0,39 = 468 kg

Action verticale Tv2 +/- (1/√1,5) x 0,39 = 0,32

F/poteau = 600 x 0,32 = +/- 192 kg

PORTIQUE FILE A / FILE B

Cas de charges

1/ Charge permanentes

Silencieux par nœud F = 600 kg

Poids propre ossature 8,40 x 16,7 x 1,10 = 154

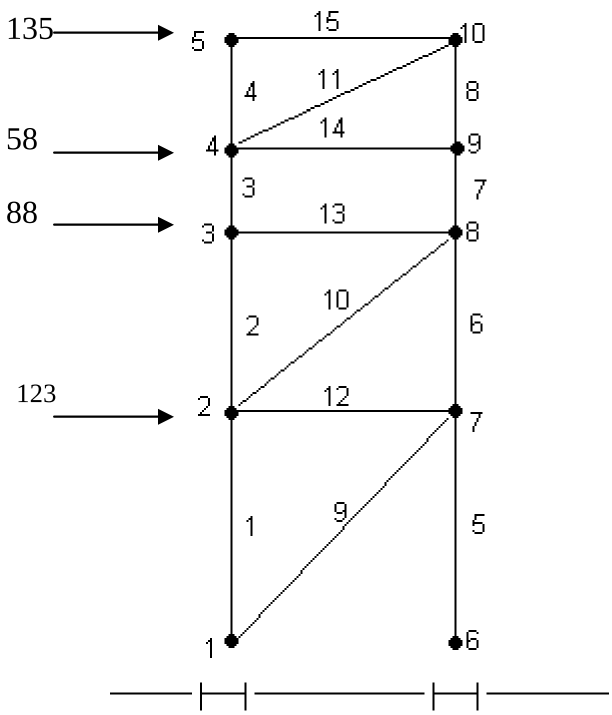
4,30/2 x 4 x 10,4 x 1,10 = 98

1,75 x 8 x 7,60 x 1,25 + 2,50 x 6 x 7,60 x 1,25 = 272

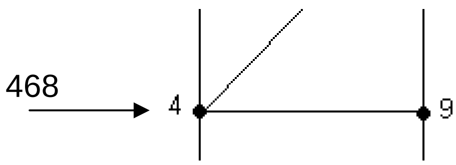
attaches et divers 56

580 kg

2/ Vent



3 /Séisme



Géomètre	1	0,00	0,00
	2	0,00	2,85
	3	0,00	5,70
	4	0,00	6,82
	5	0,00	8,385
	6	4,30	0,00
	7	4,30	2,85
	8	4,30	5,70
	9	4,30	6,82
	10	4,30	8,385

PORTIQUE FILE 1 / FILE 2

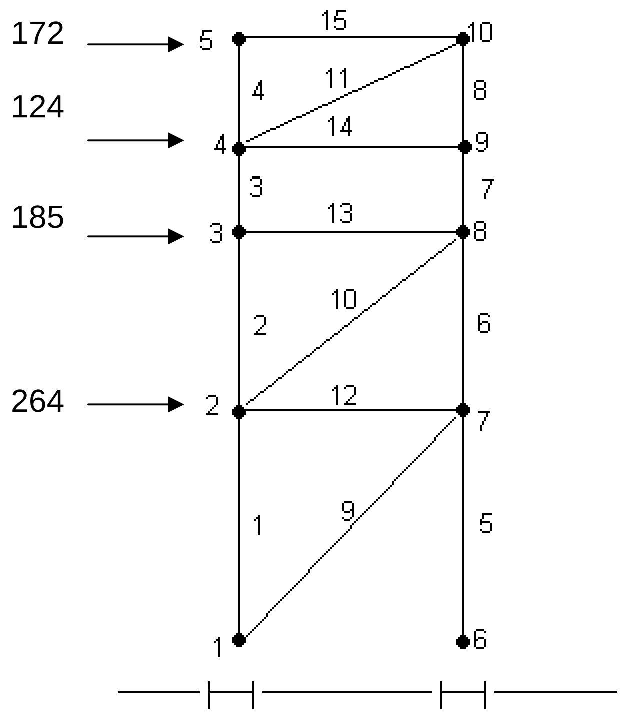
Cas de charge

1/ Charge permanente *idem précédemment*

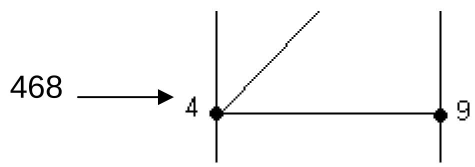
F par poteaux = 580 kg

Géomètre *idem ci-dessous car yx devient 200*

2/ Vent



3/ Séisme



VERIFICATION DES SECTIONS

1/ Poteaux

Fcp = 580 kg

Vent transversale

Vt F = 2065 x 1,75 = 3614 kg

Séisme < Vt

Vent longitudinal

Vl F = 555 x 1,75 = 971 kg

Séisme F= 763 kg

➾F = 580 + 971 = 1551

➾M = 217 kg m

HEA 120 TJ = 217/106 = 2,06 kg / m²

Tc = 1551/25 = 0.61 kg / m²

② = 285 / 3,02 = 94 h = 1,743

Par construction **HEA 120** ➾T < 24 kg / m²

2/ Diagonale

Sens T Vt = 1306 kg (t)

S = 818 kg (t)

Sens L Vt = 474 kg (t)

S = 690 kg (t)

Par construction 60 x 50 x 5 (Snet = 800 m²)

3/ Montant Horizontaux Transversaux

Barre 13 – 14 – 15 – 16

Fc = 748 x 1,75 = 1309 kg y = 2,00 micron

② = 200 / 1,51 = 132 h = 2,936

T = 1309 x (2,936/960) = 4,00 < 24 kg /m²

Par construction **60 x 50 x5**

4/ Montant horizontaux Longitudinaux (sauf support de silencieux)

Barre 12 – 13 – 14 – 15

Fc = 421 x 1,75 = 737 kg
② = 430 / 3,13 = 137 h = 2,554

T = 737 x (2,554 / 971) < 24 kg / m²

Par construction | 80 x 80 x3 |

5/ Montant Intérieur support de silencieux à plus de 6,920

fg = 2,00 n Fcp = 1000 kg (cl/2 par axe)
M = 600 x (3/2) x (2,00/4) = 450 kg.m

T = 450/41,2 = 5,16 kg/ m² < 24

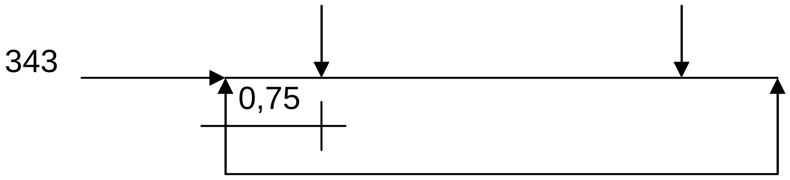
Par construction | PN 100 |

6/ Montant longitudinaux support de silencieux

Fc Vt = 142 kg x 1,75 = 249 kg
S = 343

Action verticale due au séisme +/- 192 kg

Cp 600 600
192 192

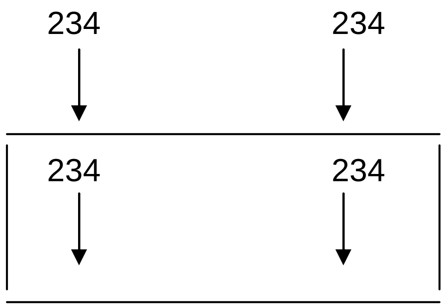


Mf Max Sans séisme = 600 x 0,75 = 450 → x 3/2 = 675 kg.m

Avec séisme = (600 + 192) x 0,75 = 594 kg.m

Action horizontale due au séisme

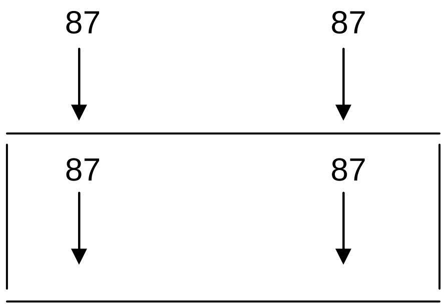
Fh = 600 x 0,39 = 234 kg par fer



M = 234 x 0,75 = 176 kg.m

Action horizontale due au vent transversal

F/Silencieux = 78 x 0,55 x 1,10 x 3,68 = 174 kg



M = 87 x 0,75 = 65 kg.m

CP + Séisme — Mv = 450 kg.m

Mh = 176 kg.m
(Fc Séisme dans l'autre sens)

Tfx = 450 / 106 = 4,24 kg/m²
Tfy = 176 / 38 = 4,43 kg/m²

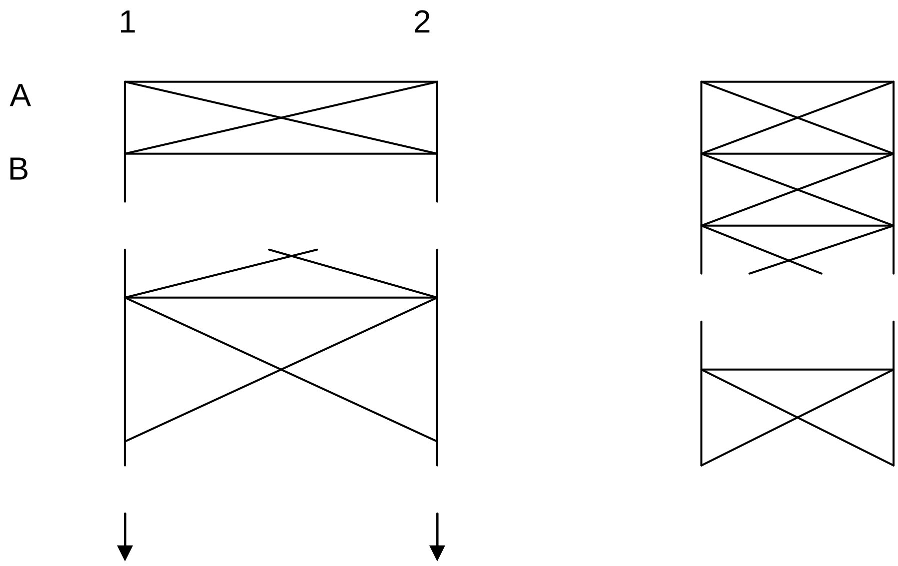
⇒T < 24 HEA 120
HEA 120

7/ Fer supérieur de ceinturage niveau + 8,385

idem HEA 120 Par construction

DESCENTES DE CHARGES

Action non pondérée de la charpente sur les massifs



	A1	A2	B1	B2	
Fz	+ 700	+7 00	+ 700	+ 700	**CP**
Fz	+ 600	+ 600	+ 600	+ 600	**Silencieux**
Fz **Fx**	- 700 + 500	+ 700	- 700 + 500	+ 700	**Vent X+**
Fz **Fx**	+ 700	- 700 - 500	+ 700	- 700 - 500	**Vent X-**
Fz **Fy**	+ 2300	+ 2300	- 2300 + 900	- 2300 + 900	**Vent Y +**
Fz **Fy**	- 2300 - 900	- 2300	+ 2300	+ 2300	**Vent Y -**
Fz **Fx**	- 900 + 600	+ 900	- 900 + 600	+ 900	**Séisme X +**
Fz **Fx**	+ 900	- 900 - 600	+ 900	- 900 - 600	**Séisme X -**
Fz **Fy**	+ 1800	+ 1800	- 1800 + 600	- 1800 + 600	**Séisme Y +**
Fz **Fy**	- 1800 - 600	- 1800 - 600	+ 1800	+ 1800	**Séisme Y -**

PIEDS DE POTEAUX

1/ Charges descendantes – Pression sur le béton

CP	= 700 kg	5325 kg
Silencieux	= 600 kg	
Vt	= 2300 x 1,75 = 4025 kg	

Tb = 53260/140² = 2,72 Mpa < 8,50

Ciment classe 45
Dosé à 350 kg/m³
Conditions courantes
Sans auto contrôle surveillé

Ep de la platine

a = 104
b = 72 b/a = 0,69 h = 0,108
c = 10 c/b = 0,14

Mmoy = 0,108 x 0,272 x 104² = 318 kg.m

$$T_{min} = \sqrt{\frac{6 \times 318 \times 0{,}8}{1{,}185 \times 24}} = 7{,}33 \text{ mn} \longrightarrow 10 \text{ mn}$$

Ep Platine 10 mn

2/ Charges ascendantes

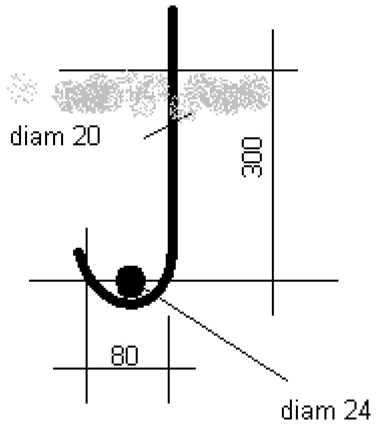
CP = 700 kg
Silencieux = 600 kg
Vt = - 2300 x 1,75

2725 kg

1363 kg / tige

2 & 20 E 24 2

ld = 30 cm



3/ Effort horizontal

F = 900 x 1,75 = 1575 kg

Bêche HEA 100 lg 130 cm

Anexo 8: Especificaciones fabricante

PERFORMANCE DATA

3600 Family

1845-7670 hp
1375-5720 kW

Generator Sets

CATERPILLAR® ENGINE SPECIFICATIONS

Bore — mm (in) 280 (11.0)
Stroke — mm (in) 300 (11.8)
Displacement — L (cu in) 18.5 (1127)
Aspiration . . . . Turbocharged-Aftercooled
Compression ratio 13:1
Rotation . . . . ccw or cw
Low Idle Speed — rpm 300-400
Rated Speed — rpm 720-1000
Avg. Piston Speed—m/s (ft/s) 7.2-10.0 (23.6-32.8)
BMEP — bar (psi)
Continuous 20.0-21.7 (290-314)
Prime. 22.0-23.9 (319-347)
Standby 24.2-26.3 (351-382)
BSFC (with pumps) — g/kW-h (lb/hp-h)
Continuous . . . . 187-199 (.307-.327)
Prime. . . . . 186-199 (.306-.327)
Standby . . . . 186-199 (.306-.327)

RATING CONDITIONS

All Industry Voltages are Available

Ratings – Generator Set ratings are in electrical kilowatts, operating on distillate fuel.
Continuous – Power and speed capabilities of the engine which can be used without interruption of load — capable of 10% overload.
Prime – For electrical service with variable loads — capable of 10% overload.
Standby – for electrical service during interruption of normal power.
Power – ±5% power tolerance applicable for overload/fuel stop power.
Fuel consumption – is based on ISO3046/1 with +5% tolerance for distillate fuel having an LHV of 42 780 kJ/kg (18,390 BTU/lb) and density or 838.9 g/liter (7.001 lbs/U.S. gal.). Including all associated pumps.
Heavy Fuel continuous ratings are 9% less than distillate fuel. Prime and standby ratings are not available. Fuel viscosity and contaminant capability is CIMAC Class K55 (700 cSt at 50°C) at 720-1000 rpm.
Description – Caterpillar® 3600 Generator Sets are designed to provide reliable and durable service with a
wide variety of blended and bunker fuels up to 700 cSt at 50°C.
Generator Set **Displacement** kW at 720 rpm/60Hz kW at 750 rpm/50 Hz kW at 900 rpm/60 Hz kW at 1000 rpm/50Hz
Engine Model Liters
(cu. in.) Cont. Prime Stdby Cont. Prime Stdby Cont. Prime Stdby Cont. Prime Stdby
3606 110.8 1375 1525 1680 1420 1570 1730 1650 1820 2000 1760 1940 2150
6 In-line **6,764**
3608 147.8 1830 2020 2220 1890 2080 2290 2200 2420 2660 2350 2600 2860
8 In-line **9,018**
3612 221.7 2750 3050 3360 2840 3140 3460 3300 3640 4000 3520 3880 4300
12 Vee **13,527**

3616 295.6 3660 4040 4440 3780 4160 4580 4400 4840 5320 4700 5200 5720
16 Vee **18,036**

DIMENSIONAL DATA

STANDARD EQUIPMENT

Engine
Accessory module with coolant expansion tank
Base mounting
Base, with lifting provisions and vibration
isolators
Breather, crankcase
Circuit cooling system, combined or separate
Cooler, lubricating oil
Duplex filters, right/left hand
fuel, full flow
lubricating oil, full flow
Engine running relay signal
Governor, Electronic 2301A
Instrument panel, includes:
differential pressure gauges – oil filter, fuel filter,
and inlet air restriction
digital tachometer
pressure gauges – oil, fuel
temperature gauges – engine coolant,
lubricating oil, exhaust stack, and air manifold
Manifold, exhaust, dry shielded
Oil filters, centrifugal
Pumps, gear driven
aftercooler & oil cooler
fuel transfer
jacket water
lubricating oil
Shutoff, electrical 24 VDC, for:
crankcase pressure
high oil temperature
high water temperature
low oil pressure (high & low idle)
overspeed
Single or separate circuit cooling system
Starting, air
Generator
Electrical
3 phase, six leads, WYE
Class “F” insulation
Maximum voltage harmonic – not to exceed 5%
total with no single voltage harmonic above 3%
NEMA MG1-22, IEC 34-1
Overload capability 110% for two hours on prime .
and continuous ratings
Short circuit capability: 300% overcurrent for 10
seconds
Voltage waveform – less than 5% deviation
Mechanical
Bearing, two sleeve, self-lubricating
Enclosure – open drip-proof – guarded (IP23)
Mechanical balance, NEMA
Overspeed: 125% per IEC 34-1 and NEMA MG-1
Package
Performance test to ISO8528
Standard Accessories
Bearing temperature detectors

Space heaters, single phase
Stator temperature detectors
Terminal box for connections
Voltage Regulation: ±1/2% no load to full load
Paralleling capability
Power isolation transformers and/or permanent magnet excitation
Static regulator, 1 or 3 phase sensing

3600 FAMILY GENERATOR SETS

Gen Set
3606
3608
3612
3616

All data is for reference only. Data is subject to change without notice. Check TMI or contact factory for confirmation.

No radiator is included in table below.

WT		L		H		W	
kg	lb	mm	in	mm	in	mm	in
34,070	74,970	7950	313	3330	131	2425	96
41,390	91,050	9240	364	3330	131	2425	96
51,230	112,690	8970	353	3710	146	2515	99
64,470	141,840	10,260	404	3790	149	2515	99

Anexo 9: Configuración del grupo

TRACTAFRIC MAROC

Casablanca, le 29 juillet 2006

TO : M. B. VERON
P. CHOUREAU

Vous passons la commande des deux 3612 « SIEMENS »

COMMANDE N° -03 & -03

MODELE : G.E. **TYPE** : 3612 EPG **QUANTITE** : 02

SPECIFICATIONS :

2 X FULDSTL	DISTILLATE FUEL
2 X 50HERTZ	50 HERTZ
2 X PBCNTNU	CONTINUOUS POWER APPLICATION
2 X KWR3520	3520 EKW
2 X 1000RPM	1000 RPM
2 X TURBO05	TURBOCHARGER GP-BASIC 254
2 X 612DE01	3612 EPG
2 X SRVRHSV	RIGHT HAND SERVICE SIDE
2 X ELTAIR1	START AIR PRESSURE
2 X ELT0024	24 VOLT DC POWER
2 X ENGACC1	ENGINE AND ACCESSORIES
2 X TWOBRG4	TWO BEARING PCKGNG-NON FACTORY
2 X REQNONE	NO SPECIAL REQUIREMENTS
2 X NOBASE1	NO BASE
2 X ACCMOD1	ACCESSORY MODULE
2 X FLY0021	FLYWHEEL-STANDARD
2 X TORCPL2	TORSIONAL COUPLING-TWO BRG GEN
2 X VLTOTHR	OTHER VOLTAGE
2 X CODE000	GENERATOR CODE UNKNOWN
2 X FLYGD05	CUST. PROVIDED FLY/CPLG GUARD
2 X DAMPGD4	DAMPER GUARD - STANDARD
2 X WELDPL2	WELD PLATES-MTG FOOT TO BASE
2 X PCGTBL2	TERMINAL BOX LOCATION - RIGHT
2 X LFTEYE1	ENGINE LIFTING EYES
2 X BARDEV2	MANUAL BARRING DEVICE - 1:1
2 X GOVEL09	GOV GP-2301A LOAD SHARE
2 X GVISOCH	GOVERNOR ISOCHRONOUS SETTING

2 X ACTEGB1	ACTUATOR-EGB HYDRA-ELECTRIC
2 X ACTSHT1	SHUTDOWN-FWD ACT ENRGD TO RUN

Suite commande 2 X 3612 "SIEMENS"

2 X SNGLCK1	SINGLE/COMBINED CIRCUIT
2 X EXPTK08	EXP TANK-HI VOL-ACC MOD MOUNT
2 X TSTAT01	THERMOSTAT-50 DEG C
2 X JWHCN01	JACKET WATER HEATER CONN ONLY
2 X WTRCNLH	WATER CONNECTIONS- LEFT HAND
2 X LHBUILD	BUILD FOR LH WATER CONNECTIONS
2 X NOWTPMP	NO ENGINE MTD AUX WATER PUMP
2 X OPADRN5	OIL PAN DRAIN VALVE-FRONT MTD
2 X DOFLT01	DUPLEX OIL FILTER
2 X INTRPRE	INTERMITTENT PRELUBE PUMP
2 X PUMPA02	PRELUBE-AIR DRIVEN
2 X MANFPP1	MANUAL FUEL PRIMING PUMP
2 X DPLXFU1	DPLX FUEL STRAINER-ACC MOD MNT
2 X FUFLX01	FLEXIBLE FUEL CONNECTION
2 X AIA0005	AIR INLET ADAPTER (90 DEG)
2 X ACLRD07	ACL-STANDARD DUTY-NOR. VOL-HOR
2 X EXSHD01	EXHAUST SOFT MANIFOLD SHIELDS
4 X EXCFF19	FLEXIBLE EXH FITTING-18 INCH
16 X EXCFL12	FLANGE-EXH 18 INCH (457MM)
2 X REDVLV1	PRESSURE REDUCING VLV-3100 KPA
2 X ECPSYS5	ECP RELAY SYS-MAX PRO-ACM MNT
2 X INSPN04	MECH GAGE INST PANEL-ACM MNT
2 X GAGE002	STANDARD THERMOCOUPLES
2 X NOWH001	NO WIRING HARNESS
2 X CYLPRE2	MECH CYLINDER PRESS GA VALVE
2 X TRKSHIP	PREP FOR TRUCK SHIPMENT IN USA
2 X SET0353	3700 BKW @ 1000 RPM (4962 BHP)
2 X MSEPGGN	GENERAL EPG
2 X TVA0001	TORSIONAL ANALYSIS-GENSET
2 X SHOTRAN	OCEANIC TRANSPORT
2 X SWPT001	SHRINK WRAP + TARP-ENGINE ONLY
2 X TST0010	OVERLOAD TEST
2 X TST0006	CERTIFIED DYNAMOMETER TEST
2 X TST0007	FUEL CONSUMPTION TEST-FUEL ST
2 X TOOL012	3600 SPECIALIZED TOOLING
2 X TOOL004	TURBOCHARGER TOOL GROUP

2 X TOOL005	CYLINDER HEAD REPAIR TOOL GP
2 X DCLFREN	FRENCH DECALS
2 X LIT0006	INSTALLATION DRAWINGS
2 X LIT0002	ADDITIONAL SET OF LITERATURE
2 X LIT0003	ADDTL SER # SPECIFIC PARTS BK

Suite commande 2 X 3612 "SIEMENS".

2 X LIT0004	ADDITIONAL SERVICE MANUAL
2 X LIT0005	ADDITIONAL TECHNICAL MANUAL
2 X LITPAPR	PAPER PARTS BOOK-IN ENGLISH
2 X SPLPNT1	SPECIAL PAINT - ENGINE ONLY

EXHAUST MUFFLER FOR EACH WITH FITTING GP 7E6282 AND FLANGE GP 7E 6228.

AIR CLEANER GP 7E-5493 FOR EACH WITH ADAPTER 7E6921, AIR INLET 7E-5060 a &b, Gage 7E-7046 AND AIR FILTER SUPPORT (Drawing A 1660-01).

MOUNTING GP GENERATOR BASE, 7E-5491- 6 ISOLATORS FOR EACH GEN SET.

2 X ALTERNATORS LEROY-SOMER, TYPE LSA 5627/6P.

4400 KVA-3,520 KW ELECTRIQUE- 1000 RPM, 5500V/50HZ, AUTOMATIC VOLTAGE REGULATOR R 610 EXCITATION AREP -**OTHER SPECIFICATION, SEE FRERK OFFER N°. DCQ011-0.**

2 X AIR COOLED TABLE RADIATOR GEA.

HT & LT WATER COOLER SET FOR CAT 3612 HORIZONTAL DESIGN, CU/AL WITH EPOXY COATING.
THE SCOPE INCLUDES : COOLER MODULE WITH LEGS & 6 ELECTRIC FANS INSTALLED ELECTRIC POWER 15 KW FOR EACH.

AIR START SYSTEM FOR BOTH UNIT COMPRISING :

1 X DIESEL COMPRESSOR 30 BARS / 16m3/H.
1 X ELECTRIC COMPRESSOR 30 BARS / 16m3 /H.
2 X AIR RECEIVERS 30 BARS/710L.

2 X CUVES A HUILE USEE ET NEUVE, CAPACITE 1500 LITRES, EN ACIER E 24-2 EPAISSEUR 40/10, AVEC BAC DE RETENTION, ELECTROPOMPE JEV71- 380 TRIPHASE, CONTACT DE NIVEAU CF4, POMPE MANUELLE DE SECOURS, FILTRE A TAMIS, TRAPPE DE VISITE DIAM. 400.
EQUIPEMENT DE REMPLISSAGE ET VIDANGE SUIVANT PLAN N°. 400 BAZHH.

EQUIPEMENTS MECANIQUES :
SUIVANT OFFRE GEA/APS 3595 3612 ET PV DE REUNION APS/TAM/SIEMENS

Suite commande 2 X 3612 "SIEMENS".

EQUIPEMENTS ELECTRIQUES : COMPRENANT LES ARMOIRES DE CONTROLE COMMANDE ET DE SYNCHRONISATION SUIVANT OFFRE GEA/APS/3595-3612, PV DE REUNION APS/TAM/SIEMENS DES 17/18& 19/3 2003 ET REUNION SAMIR/SIEMENS/TAM/GEA (AVEC ALPHONSE KERIS)

M. DAFFA
TAM

Anexo 10: Lista de componentes de las instalaciones

LISTE DES COMPOSANTS Rev 03 du 16 Fev 2007

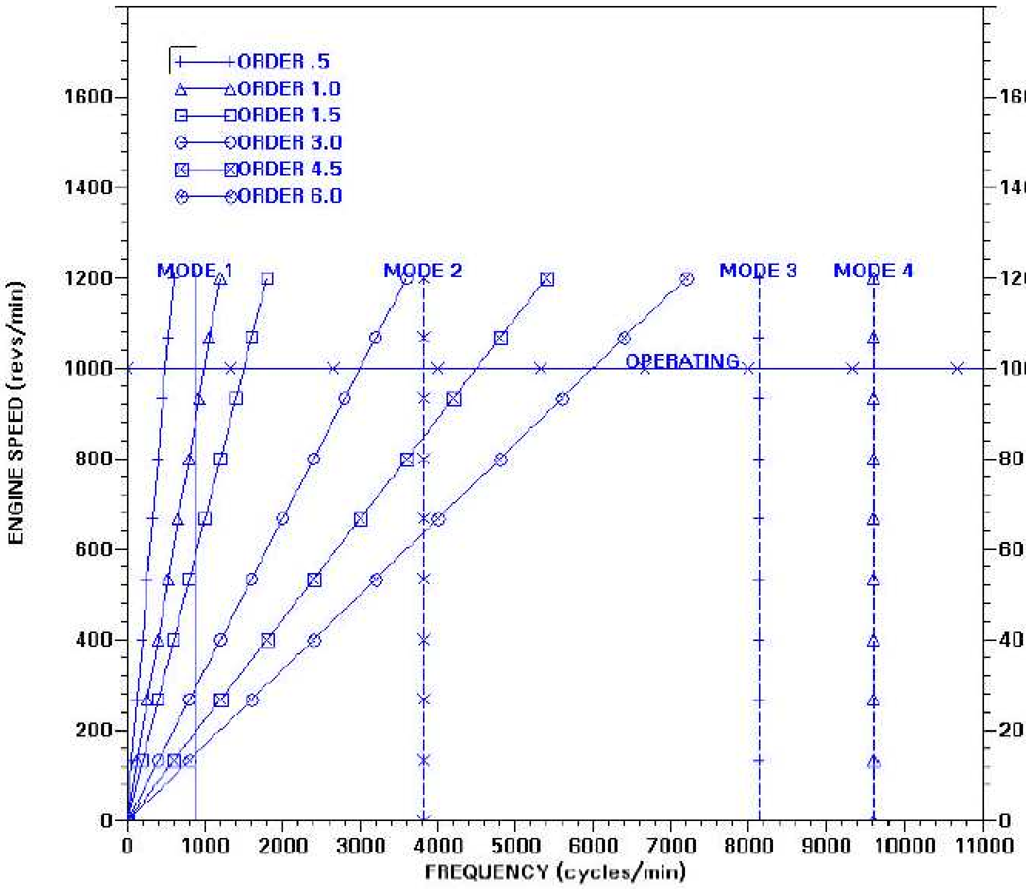
Circuits communs

Description	Manufacturer	Référence	Remarque
Circuit air comprimé			
Compresseur diesel	Neuenhauser	18.2.2.02.01.33.00	
Electrovanne	Neuenhauser		monté sur 98DA 3&4 - AN002
Electrovanne	Neuenhauser		monté sur 98DA 3&4 - AN002
Soupape de décharge	Neuenhauser		monté sur 98DA 3&4 - AN002
Soupape de décharge	Neuenhauser		monté sur 98DA 3&4 - AN002
Clapet de non retour	Neuenhauser		monté sur 98DA 3&4 - AN002
Vanne d'isolation DN20 (3/4 ") - PN64	APS / KDI	EF1025BW/SW	boisseau sphérique
Filtre à air	Neuenhauser		monté sur 98DA 3&4 - AN002
Séparateur d'eau	Neuenhauser		monté sur 98DA 3&4 - AN002
Compresseur électrique	Neuenhauser	35.2.01.01.10.21	
Electrovanne	Neuenhauser		monté sur 98DA 3&4 - AN001
Electrovanne	Neuenhauser		monté sur 98DA 3&4 - AN001
Soupape de décharge	Neuenhauser		monté sur 98DA 3&4 - AN001
Soupape de décharge	Neuenhauser		monté sur 98DA 3&4 - AN001
Clapet de non retour	Neuenhauser		monté sur 98DA 3&4 - AN001
Vanne d'isolation DN20 (3/4 ") - PN64	APS / KDI	EF1025BW/SW	boisseau sphérique
Filtre à air	Neuenhauser		monté sur 98DA 3&4 - AN001
Séparateur d'eau	Neuenhauser		monté sur 98DA 3&4 - AN001
Bouteille air comprimé n°1	Neuenhauser	71N03356	
Vanne d'isolation	Neuenhauser		monté sur 98DA 3&4 - BB001
Vanne d'isolation	Neuenhauser		monté sur 98DA 3&4 - BB001
Soupape de décharge	Neuenhauser		monté sur 98DA 3&4 - BB001
Indicateur de pression	Neuenhauser		monté sur 98DA 3&4 - BB001
Bouteille air comprimé n°2	Neuenhauser	71N03356	
Vanne d'isolation	Neuenhauser		monté sur 98DA 3&4 - BB002
Vanne d'isolation	Neuenhauser		monté sur 98DA 3&4 - BB002
Soupape de décharge	Neuenhauser		monté sur 98DA 3&4 - BB002
Indicateur de pression	Neuenhauser		monté sur 98DA 3&4 - BB002
Vanne d'isolation de 98DA3	APS / KDI	EF1025BW/SW	DN32 PN64 boisseau sphérique
Vanne d'isolation de 98DA4	APS / KDI	EF1025BW/SW	DN32 PN64 boisseau sphérique
Circuit Fuel			
Cuves principales 30,000 L			fourniture Samir
Vanne d'isolation DN65 - PN64	APS / Aquiro	304556	corps acier - sphere inox
Vanne de vidange 2"	APS / Aquiro	576 - 50/60	PN40 -boisseau sphérique laiton

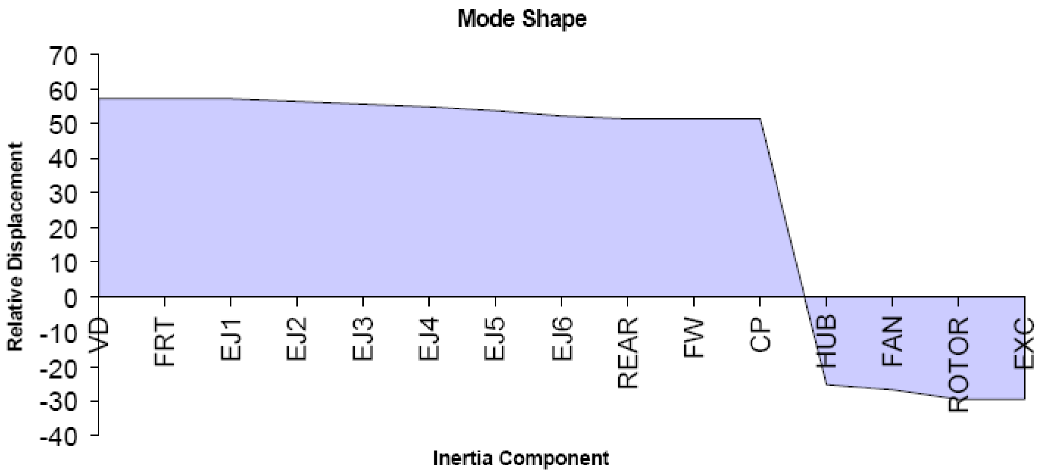
Vanne d'isolation DN ??			fourniture Samir
Vanne d'isolation DN65 - PN64	APS/KDI	304556	corps acier - sphere inox
Vanne de vidange 2"	APS / Aquiro	576 - 50/60	PN40 -boisseau sphérique laiton
Vanne d'isolation DN??			fourniture Samir
Vanne d'isolation DN65	APS/KDI	304556	corps acier - sphere inox
Vanne d'isolation DN65	APS/KDI	304556	corps acier - sphere inox
Circuit huile			
Réservoir huile neuve et usée	Rotatron	400 BA2/HH	
Vanne d'isolation	Rotatron		montée sur 98DA 3&4 - 400BA2HH
Vanne d'isolation	Rotatron		montée sur 98DA 3&4 - 400BA2HH
Vanne d'isolation	Rotatron		montée sur 98DA 3&4 - 400BA2HH
Vanne d'isolation	Rotatron		montée sur 98DA 3&4 - 400BA2HH
Vanne d'isolation	Rotatron		montée sur 98DA 3&4 - 400BA2HH
Vanne d'isolation	Rotatron		montée sur 98DA 3&4 - 400BA2HH
Vanne d'isolation	Rotatron		montée sur 98DA 3&4 - 400BA2HH
Pompe de vidange manuelle	Rotatron		montée sur 98DA 3&4 - 400BA2HH
Pompe de vidange électrique	Rotatron		montée sur 98DA 3&4 - 400BA2HH
Vanne de vidange	Rotatron		montée sur 98DA 3&4 - 400BA2HH
Vanne de dépotage	Rotatron		montée sur 98DA 3&4 - 400BA2HH
Indicateur niveau huile usée	Rotatron		montée sur 98DA 3&4 - 400BA2HH
Contact de niveau huile usée	Rotatron		montée sur 98DA 3&4 - 400BA2HH
Vanne d'isolation	Rotatron		montée sur 98DA 3&4 - 400BA2HH
Vanne d'isolation	Rotatron		montée sur 98DA 3&4 - 400BA2HH
Vanne d'isolation	Rotatron		montée sur 98DA 3&4 - 400BA2HH
Vanne d'isolation	Rotatron		montée sur 98DA 3&4 - 400BA2HH
Vanne d'isolation	Rotatron		montée sur 98DA 3&4 - 400BA2HH
Vanne d'isolation	Rotatron		montée sur 98DA 3&4 - 400BA2HH
Vanne d'isolation	Rotatron		montée sur 98DA 3&4 - 400BA2HH
Pompe de vidange manuelle	Rotatron		montée sur 98DA 3&4 - 400BA2HH
Pompe de vidange électrique	Rotatron		montée sur 98DA 3&4 - 400BA2HH
Vanne de vidange	Rotatron		montée sur 98DA 3&4 - 400BA2HH
Vanne de dépotage	Rotatron		montée sur 98DA 3&4 - 400BA2HH
Indicateur niveau huile usée	Rotatron		montée sur 98DA 3&4 - 400BA2HH
Contact de niveau huile usée	Rotatron		montée sur 98DA 3&4 - 400BA2HH

Anexo 11: Resultados simulación Análisis Vibraciones Torsionales

Resonant Speed Diagram

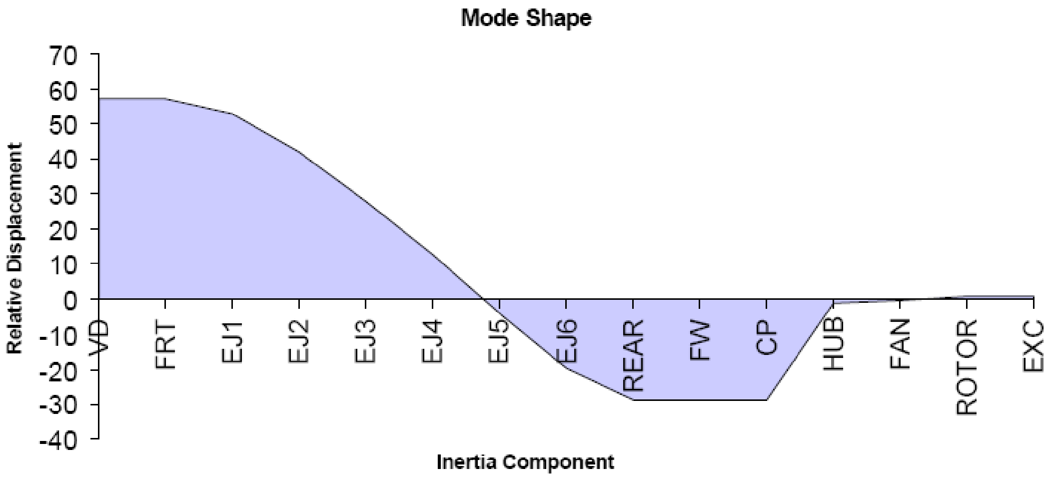


First Natural Frequency Occurs at 877 CPM



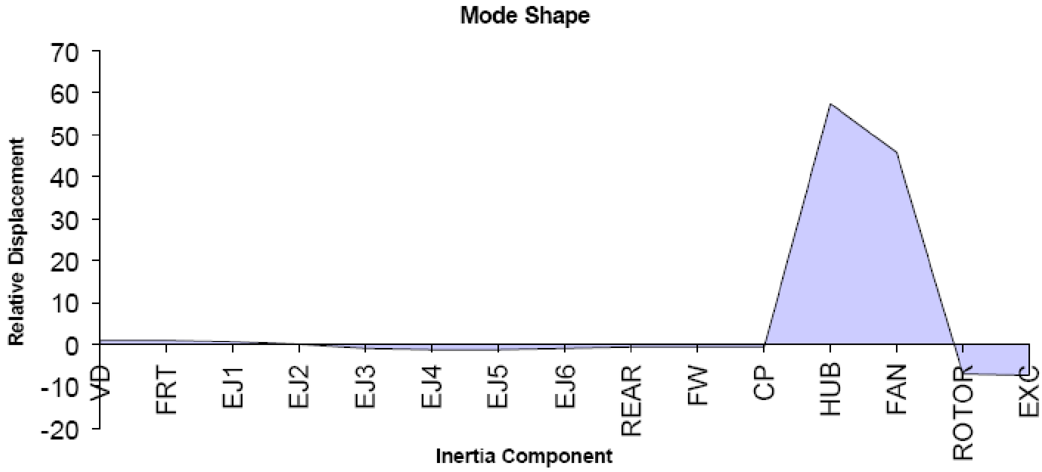
MASS ID	MASS NAME	INERTIA (N*m*sec^2)	DISPLACE (degrees)	SPRING ID	STIFFNESS (MN*m/rad)	CUM TORQUE (N*m)	DIAMETER (mm)	STRESS (MPa)
VD		2.686E+01	5.730E+01		0.000E+00	2.265E+05	0.000E+00	0.000E+00
FRT		5.645E+00	5.730E+01	EK1	6.780E+01	2.741E+05	2.160E+02	2.417E+00
EJ1		1.700E+01	5.706E+01	EK2	4.011E+01	4.168E+05	2.160E+02	3.677E+00
EJ2		1.632E+01	5.647E+01	EK3	4.011E+01	5.525E+05	2.160E+02	4.873E+00
EJ3		1.632E+01	5.568E+01	EK4	4.011E+01	6.862E+05	2.160E+02	6.052E+00
EJ4		1.632E+01	5.470E+01	EK5	4.011E+01	8.175E+05	2.160E+02	7.211E+00
EJ5		1.632E+01	5.353E+01	EK6	4.011E+01	9.461E+05	2.160E+02	8.345E+00
EJ6		1.700E+01	5.218E+01	EK7	6.780E+01	1.077E+06	2.160E+02	9.496E+00
REAR		5.826E+00	5.127E+01		0.000E+00	1.121E+06	0.000E+00	0.000E+00
FW		7.490E+01	5.127E+01		0.000E+00	1.686E+06	0.000E+00	0.000E+00
CP		5.900E+01	5.127E+01	CPK	1.600E+00	2.131E+06	0.000E+00	0.000E+00
HUB		2.030E+01	-2.504E+01	GK1	6.580E+01	2.056E+06	2.000E+02	2.285E+01
FAN		4.600E+01	-2.683E+01	GK2	4.309E+01	1.874E+06	2.100E+02	1.799E+01
ROTOR		4.287E+02	-2.932E+01	GK3	9.390E+01	2.482E+04	2.600E+02	1.255E-01
EXC		5.750E+00	-2.933E+01		0.000E+00	-2.070E-01	0.000E+00	0.000E+00

Second Natural Frequency Occurs at 3815 CPM



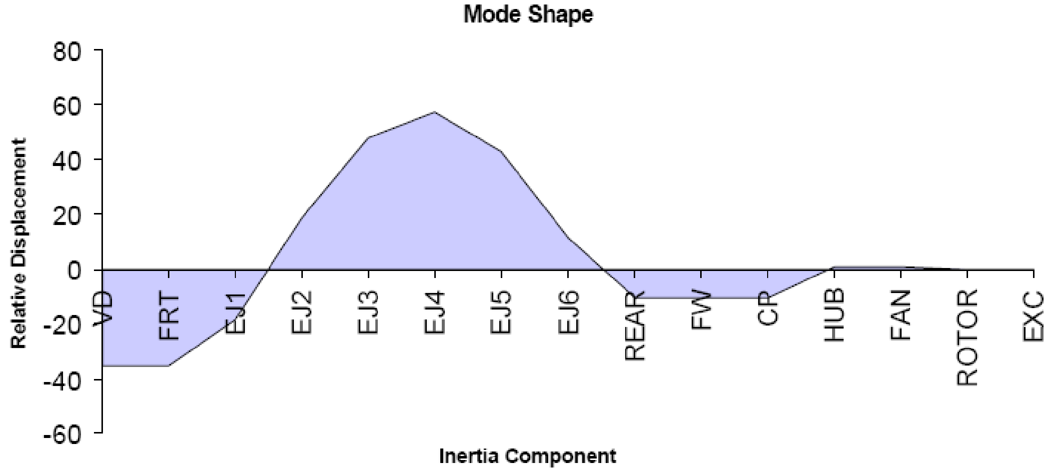
MASS ID	MASS NAME	INERTIA (N*m*sec^2)	DISPLACE (degrees)	SPRING ID	STIFFNESS (MN*m/rad)	CUM TORQUE (N*m)	DIAMETER (mm)	STRESS (MPa)
VD		2.686E+01	5.730E+01		0.000E+00	4.286E+06	0.000E+00	0.000E+00
FRT		5.645E+00	5.730E+01	EK1	6.780E+01	5.187E+06	2.160E+02	4.575E+01
EJ1		1.700E+01	5.291E+01	EK2	4.011E+01	7.692E+06	2.160E+02	6.785E+01
EJ2		1.632E+01	4.192E+01	EK3	4.011E+01	9.598E+06	2.160E+02	8.465E+01
EJ3		1.632E+01	2.821E+01	EK4	4.011E+01	1.088E+07	2.160E+02	9.597E+01
EJ4		1.632E+01	1.267E+01	EK5	4.011E+01	1.146E+07	2.160E+02	1.010E+02
EJ5		1.632E+01	-3.691E+00	EK6	4.011E+01	1.129E+07	2.160E+02	9.957E+01
EJ6		1.700E+01	-1.982E+01	EK7	6.780E+01	1.035E+07	2.160E+02	9.129E+01
REAR		5.826E+00	-2.856E+01		0.000E+00	9.887E+06	0.000E+00	0.000E+00
FW		7.490E+01	-2.856E+01		0.000E+00	3.928E+06	0.000E+00	0.000E+00
CP		5.900E+01	-2.856E+01	CPK	1.600E+00	-7.649E+05	0.000E+00	0.000E+00
HUB		2.030E+01	-1.171E+00	GK1	6.580E+01	-8.311E+05	2.000E+02	9.235E+00
FAN		4.600E+01	-4.471E-01	GK2	4.309E+01	-8.884E+05	2.100E+02	8.527E+00
ROTOR		4.287E+02	7.341E-01	GK3	9.390E+01	-1.187E+04	2.600E+02	6.005E-02
EXC		5.750E+00	7.414E-01		0.000E+00	-4.482E-01	0.000E+00	0.000E+00

Third Natural Frequency Occurs at 8144 CPM



MASS ID	MASS NAME	INERTIA (N*m*sec^2)	DISPLACE (degrees)	SPRING ID	STIFFNESS (MN*m/rad)	CUM TORQUE (N*m)	DIAMETER (mm)	STRESS (MPa)
VD		2.686E+01	9.434E-01		0.000E+00	3.217E+05	0.000E+00	0.000E+00
FRT		5.645E+00	9.434E-01	EK1	6.780E+01	3.893E+05	2.160E+02	3.434E+00
EJ1		1.700E+01	6.144E-01	EK2	4.011E+01	5.219E+05	2.160E+02	4.603E+00
EJ2		1.632E+01	-1.311E-01	EK3	4.011E+01	4.947E+05	2.160E+02	4.364E+00
EJ3		1.632E+01	-8.378E-01	EK4	4.011E+01	3.211E+05	2.160E+02	2.833E+00
EJ4		1.632E+01	-1.297E+00	EK5	4.011E+01	5.252E+04	2.160E+02	4.633E-01
EJ5		1.632E+01	-1.372E+00	EK6	4.011E+01	-2.316E+05	2.160E+02	2.043E+00
EJ6		1.700E+01	-1.041E+00	EK7	6.780E+01	-4.562E+05	2.160E+02	4.024E+00
REAR		5.826E+00	-6.551E-01		0.000E+00	-5.047E+05	0.000E+00	0.000E+00
FW		7.490E+01	-6.551E-01		0.000E+00	-1.128E+06	0.000E+00	0.000E+00
CP		5.900E+01	-6.551E-01	CPK	1.600E+00	-1.618E+06	0.000E+00	0.000E+00
HUB		2.030E+01	5.730E+01	GK1	6.580E+01	1.315E+07	2.000E+02	1.461E+02
FAN		4.600E+01	4.585E+01	GK2	4.309E+01	3.992E+07	2.100E+02	3.832E+02
ROTOR		4.287E+02	-7.234E+00	GK3	9.390E+01	5.526E+05	2.600E+02	2.795E+00
EXC		5.750E+00	-7.571E+00		0.000E+00	1.260E+00	0.000E+00	0.000E+00

Fourth Natural Frequency Occurs at 9611 CPM



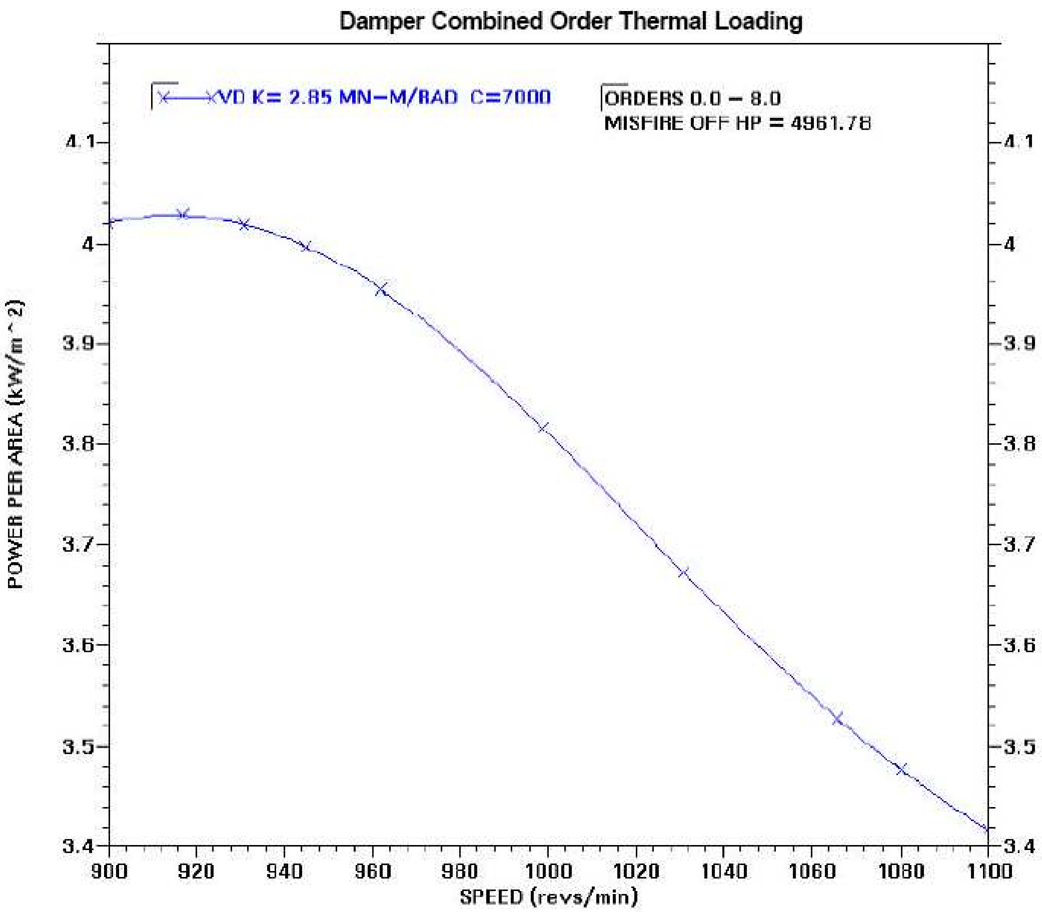
MASS ID	MASS NAME	INERTIA (N*m*sec^2)	DISPLACE (degrees)	SPRING ID	STIFFNESS (MN*m/rad)	CUM TORQUE (N*m)	DIAMETER (mm)	STRESS (MPa)
VD		2.686E+01	-3.539E+01		0.000E+00	-1.681E+07	0.000E+00	0.000E+00
FRT		5.645E+00	-3.539E+01	EK1	6.780E+01	-2.034E+07	2.160E+02	1.794E+02
EJ1		1.700E+01	-1.820E+01	EK2	4.011E+01	-2.581E+07	2.160E+02	2.276E+02
EJ2		1.632E+01	1.867E+01	EK3	4.011E+01	-2.042E+07	2.160E+02	1.801E+02
EJ3		1.632E+01	4.784E+01	EK4	4.011E+01	-6.620E+06	2.160E+02	5.839E+01
EJ4		1.632E+01	5.730E+01	EK5	4.011E+01	9.913E+06	2.160E+02	8.743E+01
EJ5		1.632E+01	4.314E+01	EK6	4.011E+01	2.236E+07	2.160E+02	1.972E+02
EJ6		1.700E+01	1.120E+01	EK7	6.780E+01	2.572E+07	2.160E+02	2.269E+02
REAR		5.826E+00	-1.054E+01		0.000E+00	2.464E+07	0.000E+00	0.000E+00
FW		7.490E+01	-1.054E+01		0.000E+00	1.068E+07	0.000E+00	0.000E+00
CP		5.900E+01	-1.054E+01	CPK	1.600E+00	-3.208E+05	0.000E+00	0.000E+00
HUB		2.030E+01	9.466E-01	GK1	6.580E+01	1.891E+04	2.000E+02	2.101E-01
FAN		4.600E+01	9.302E-01	GK2	4.309E+01	7.754E+05	2.100E+02	7.443E+00
ROTOR		4.287E+02	-1.009E-01	GK3	9.390E+01	1.093E+04	2.600E+02	5.528E-02
EXC		5.750E+00	-1.075E-01		0.000E+00	-1.430E+00	0.000E+00	0.000E+00

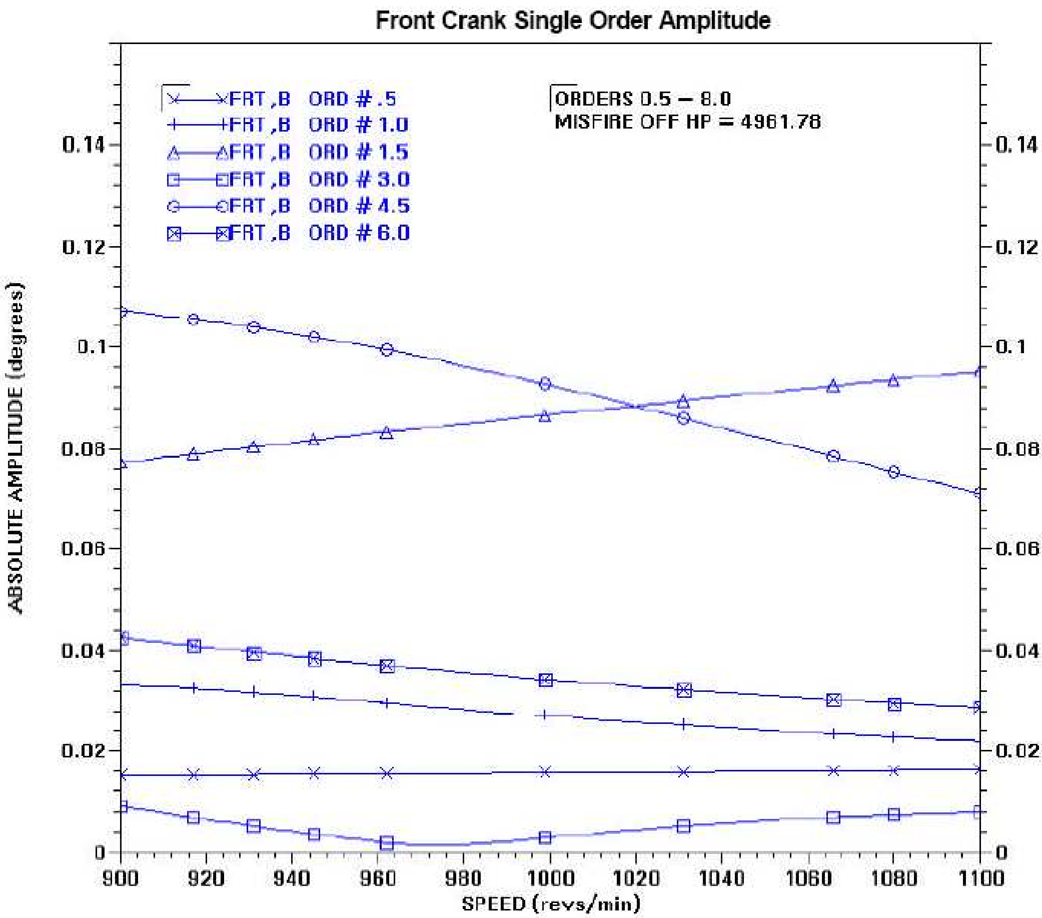
Single Order Results		Order	Predicted	Permissible Limit
FRT	Absolute Amplitude (deg)	0.5	0.016	1.00
	Absolute Amplitude (deg)	1.0	0.033	1.00
	Absolute Amplitude (deg)	1.5	0.095	0.25
	Absolute Amplitude (deg)	3.0	0.009	0.15
	Absolute Amplitude (deg)	4.5	0.107	0.15
	Absolute Amplitude (deg)	6.0	0.043	0.15
EK5	Vibratory Stress (MPa)	0.5	1.62	21.0
	Vibratory Stress (MPa)	1.0	12.99	21.0
	Vibratory Stress (MPa)	1.5	12.97	21.0
	Vibratory Stress (MPa)	3.0	2.07	21.0
	Vibratory Stress (MPa)	4.5	10.94	21.0
	Vibratory Stress (MPa)	6.0	3.21	21.0
GK1	Vibratory Stress (MPa)	0.5	0.06	34.5
	Vibratory Stress (MPa)	1.0	0.75	34.5
	Vibratory Stress (MPa)	1.5	1.52	34.5
	Vibratory Stress (MPa)	3.0	0.59	34.5
	Vibratory Stress (MPa)	4.5	1.00	34.5
	Vibratory Stress (MPa)	6.0	0.17	34.5
	Vibratory Stress (MPa)	7.5	0.30	34.5
	Vibratory Stress (MPa)	8.0	0.45	34.5

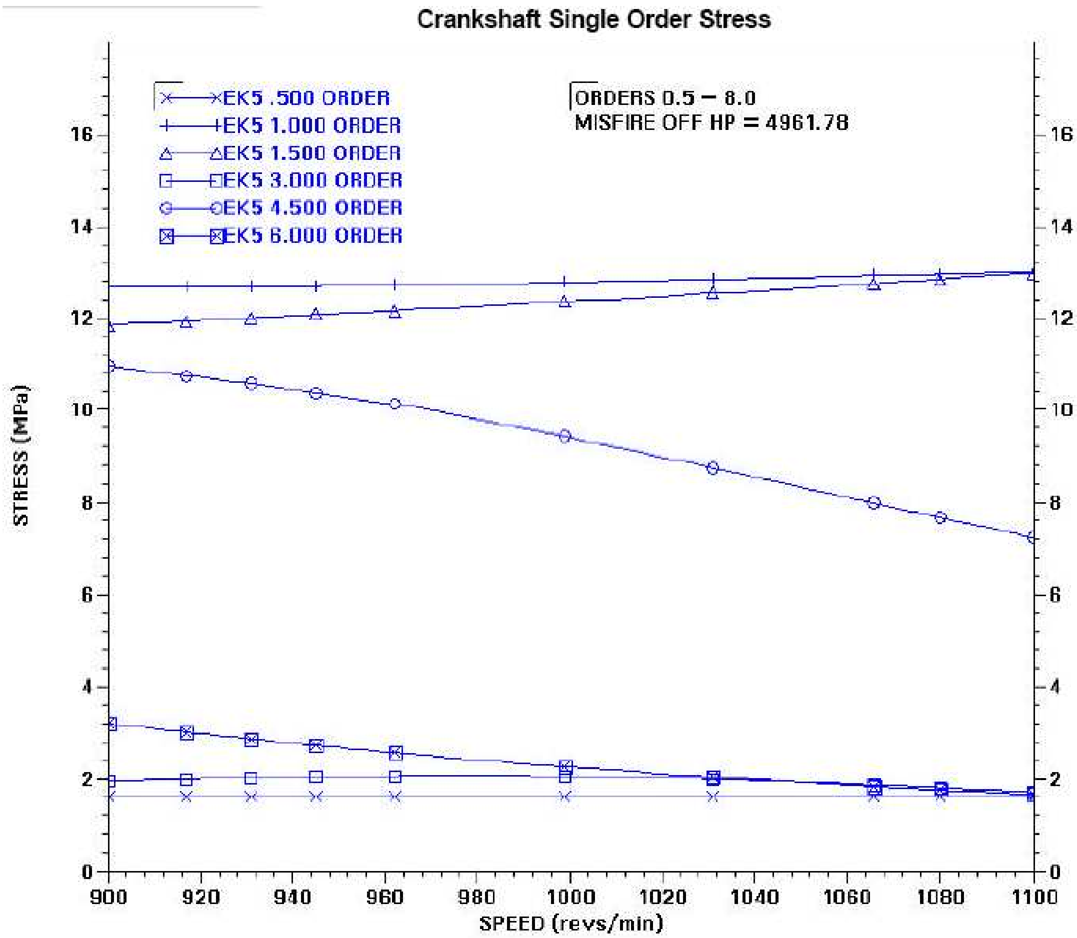
Combined Order Results		Predicted	Permissible Limit
VD	Power Absorbed (kW/m^2)	4.0	5.7
CPK	Maximum Torque (Nm)	41522	134000
	Vibratory Torque (Nm)	5471	25200
	Nominal Torque (Nm)	35332	63000
	Power Loss (kW)	0.15	1.06

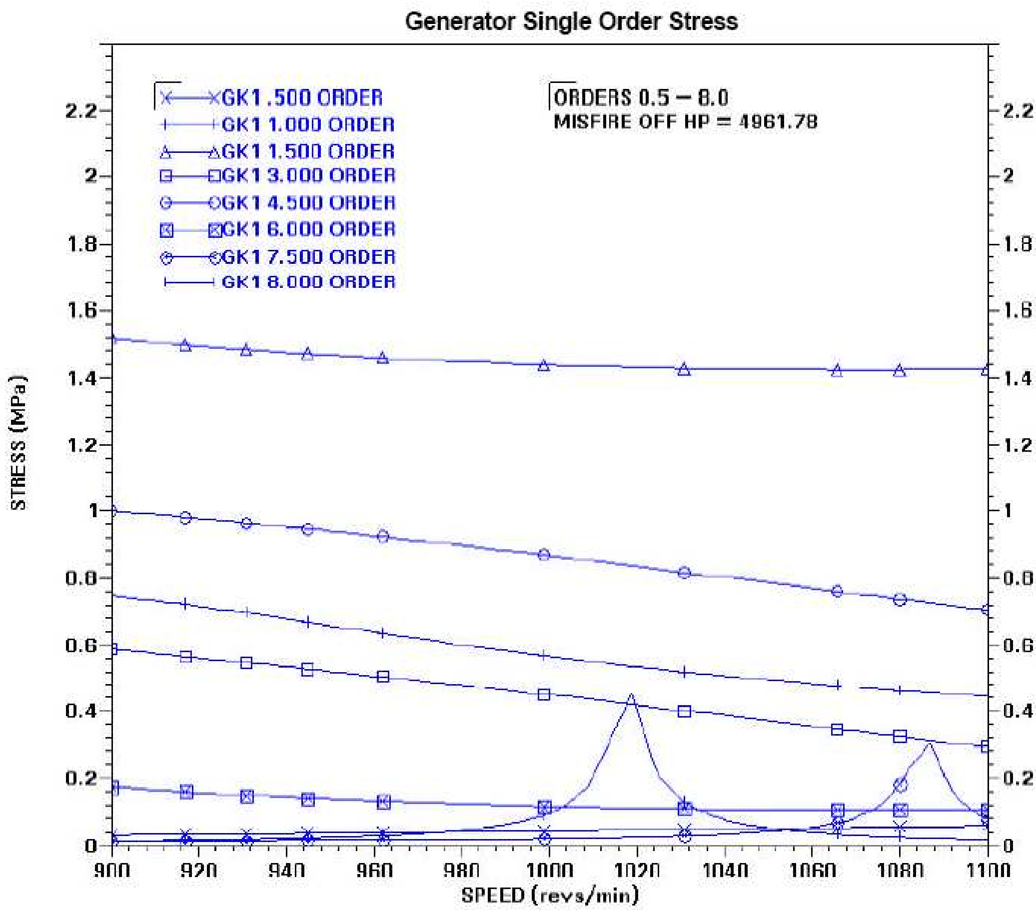
Single Order Misfire Results		Order	Predicted	Permissible Limit
FRT	Absolute Amplitude (deg)	0.5	0.081	1.00
	Absolute Amplitude (deg)	1.0	0.510	1.00
EK5	Vibratory Stress (MPa)	0.5	4.21	21.0
	Vibratory Stress (MPa)	1.0	16.50	21.0
GK1	Vibratory Stress (MPa)	0.5	3.79	34.5
	Vibratory Stress (MPa)	1.0	11.72	34.5

Combined Order Misfire Results		Predicted	Permissible Limit
VD	Power Absorbed (kW/m^2)	4.0	5.7
CPK	Maximum Torque (Nm)	61179	134000
	Vibratory Torque (Nm)	24186	25200
	Nominal Torque (Nm)	35332	63000
	Power Loss (kW)	2.02	1.06
Engine misfire may cause significant torsional vibration in the coupling, as indicated by high vibratory torque and power loss levels. This vibration would cause the coupling rubber elements to warm, changing their elastic properties. See warm coupling results beginning on page 25 for a more accurate representation of engine misfire behavior.			

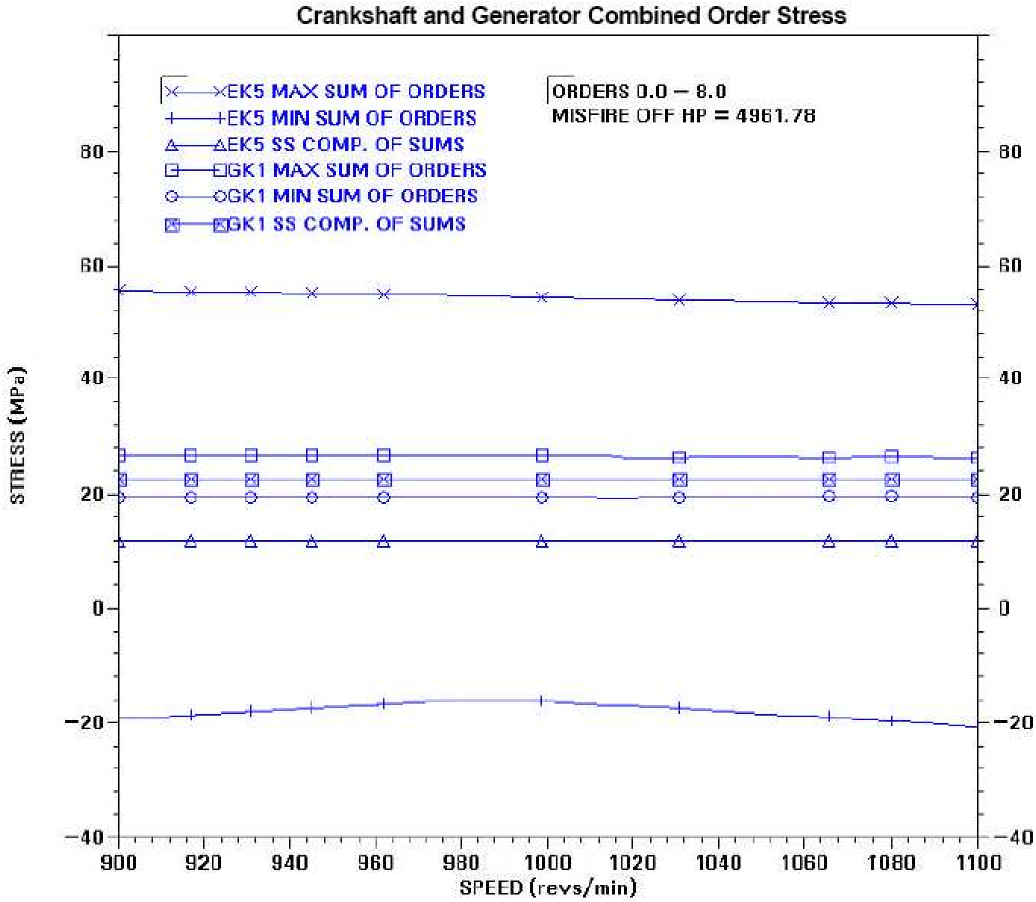

Damper Combined Order Thermal Loading
VD K= 2.85 MN-M/RAD C=7000
ORDERS 0.0 - 8.0
MISFIRE OFF HP = 4961.78
POWER PER AREA (kW/m^2)
SPEED (revs/min)
4.1
4
3.9
3.8
3.7
3.6
3.5
3.4
900
920
940
960
980
1000
1020
1040
1060
1080
1100

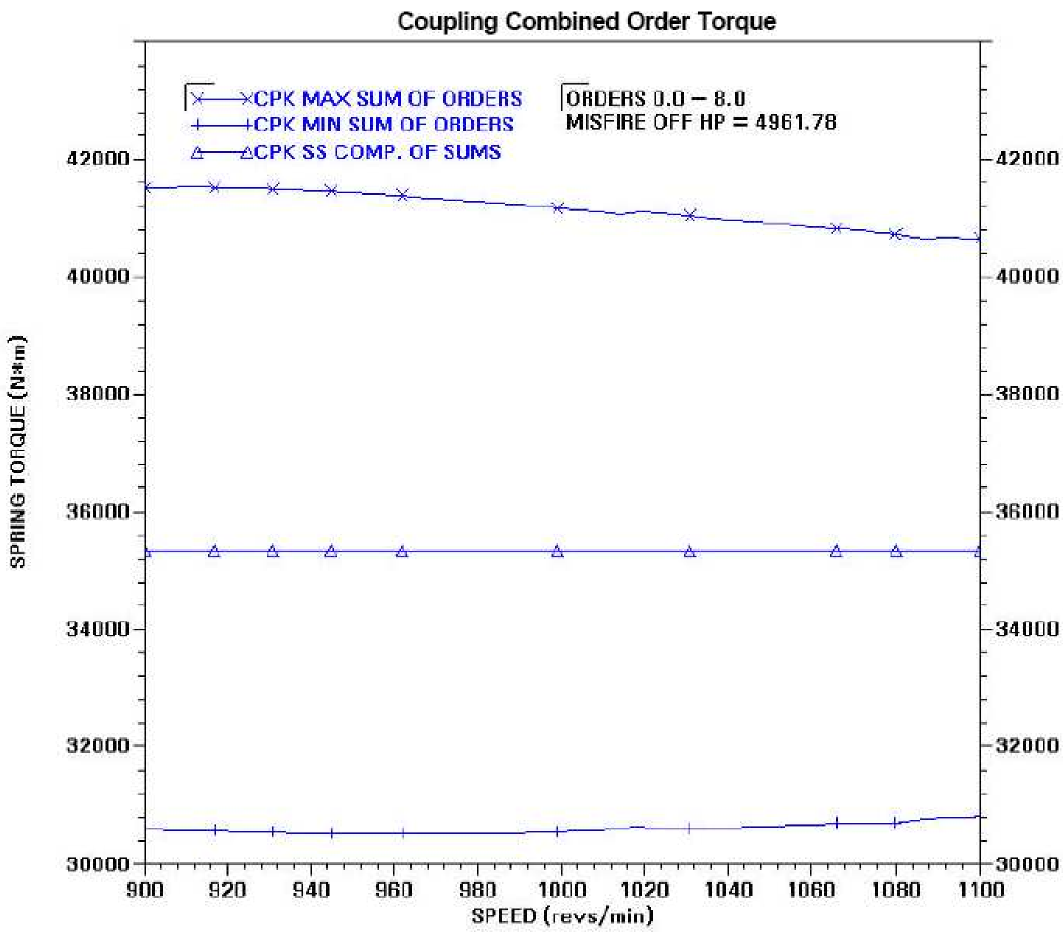

Front Crank Single Order Amplitude
FRT ,B ORD # .5
FRT ,B ORD # 1.0
FRT ,B ORD # 1.5
FRT ,B ORD # 3.0
FRT ,B ORD # 4.5
FRT ,B ORD # 6.0
ORDERS 0.5 – 8.0
MISFIRE OFF HP = 4961.78
ABSOLUTE AMPLITUDE (degrees)
SPEED (revs/min)
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
900
920
940
960
980
1000
1020
1040
1060
1080
1100

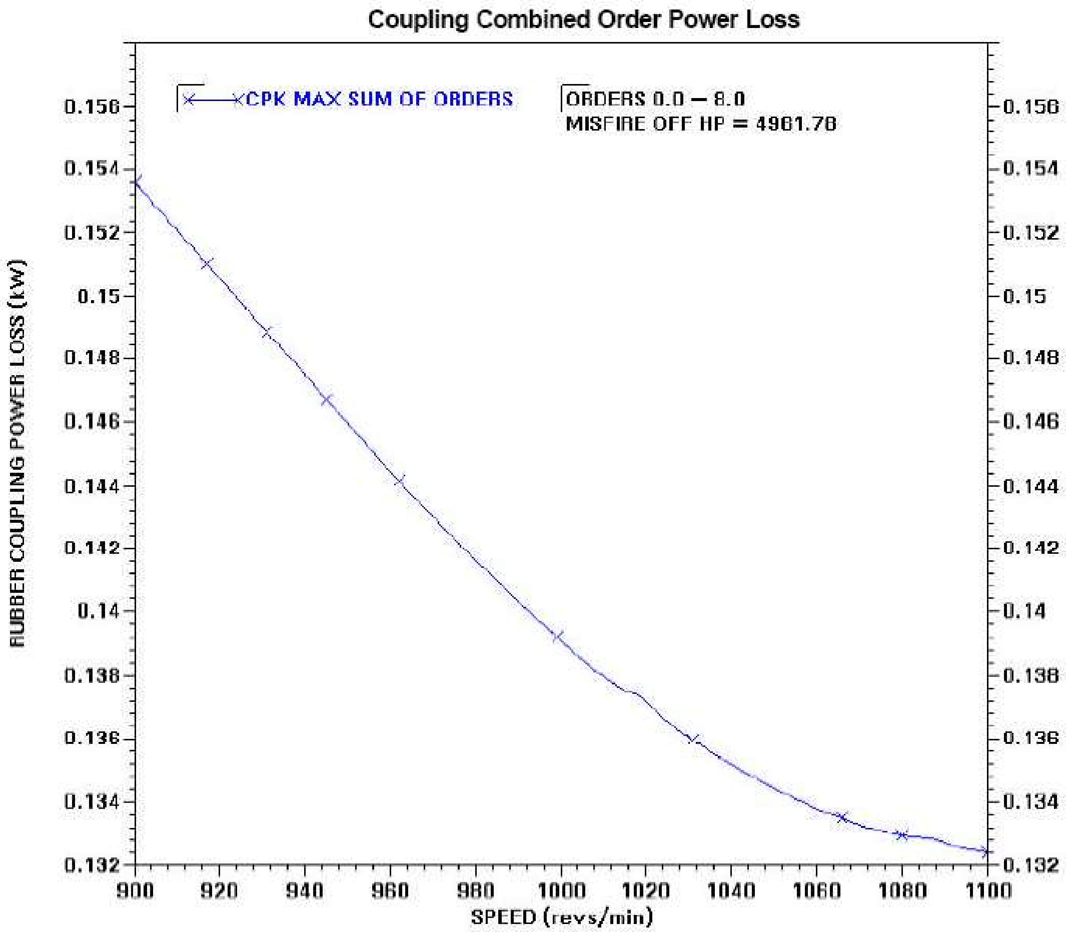

Crankshaft Single Order Stress
EK5 .500 ORDER
EK5 1.000 ORDER
EK5 1.500 ORDER
EK5 3.000 ORDER
EK5 4.500 ORDER
EK5 6.000 ORDER
ORDERS 0.5 – 8.0
MISFIRE OFF HP = 4961.78
STRESS (MPa)
SPEED (revs/min)
0
2
4
6
8
10
12
14
16
900
920
940
960
980
1000
1020
1040
1060
1080
1100

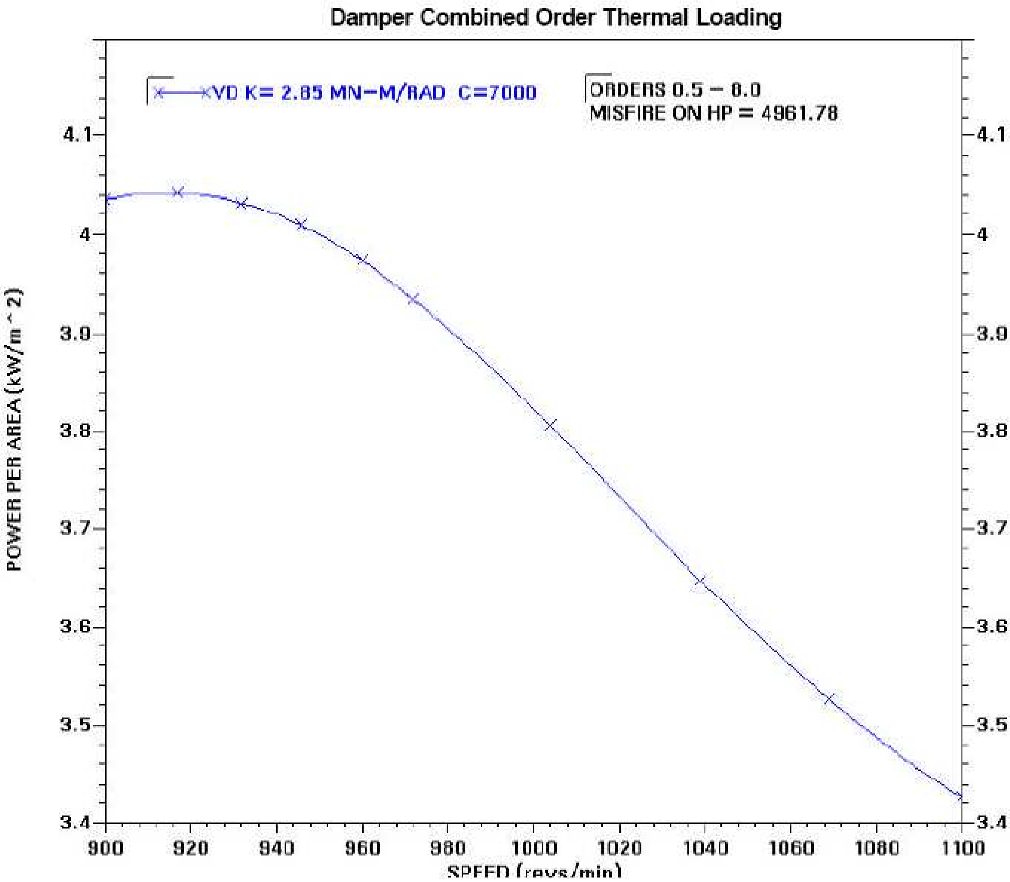


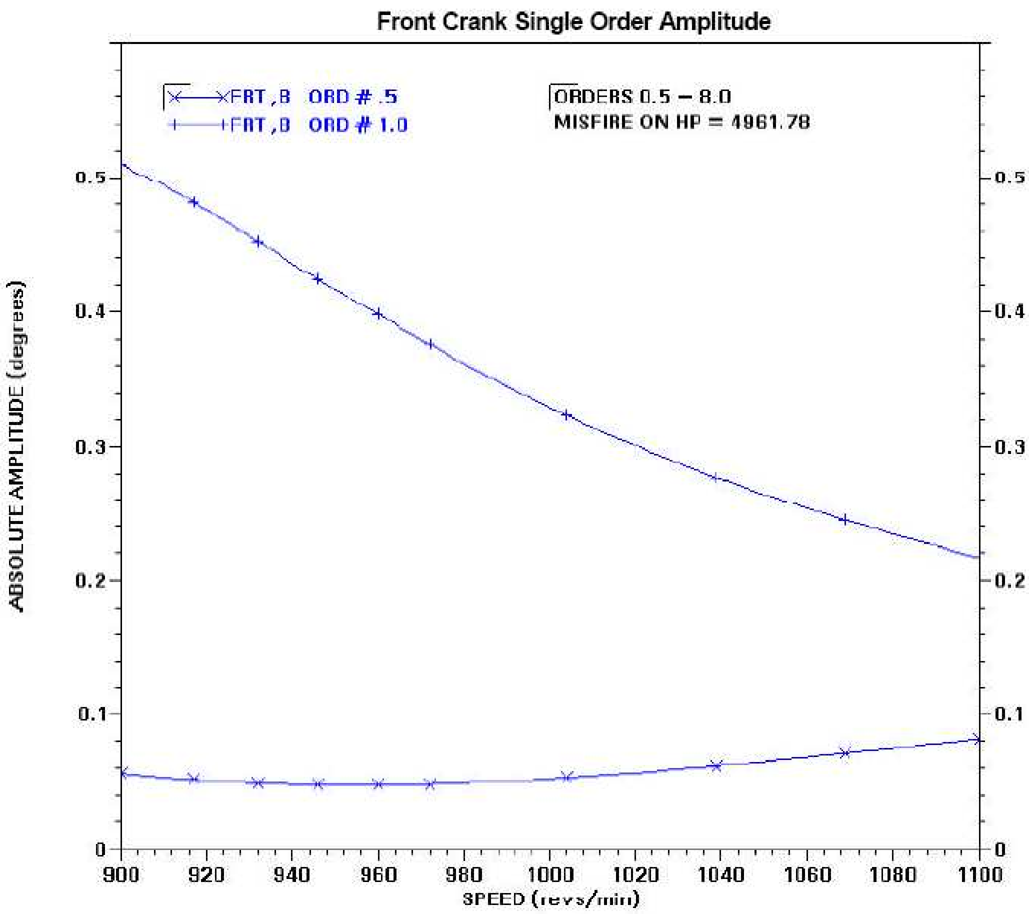
Generator Single Order Stress
GK1 .500 ORDER
GK1 1.000 ORDER
GK1 1.500 ORDER
GK1 3.000 ORDER
GK1 4.500 ORDER
GK1 6.000 ORDER
GK1 7.500 ORDER
GK1 8.000 ORDER
ORDERS 0.5 – 8.0
MISFIRE OFF HP = 4961.78
STRESS (MPa)
SPEED (revs/min)

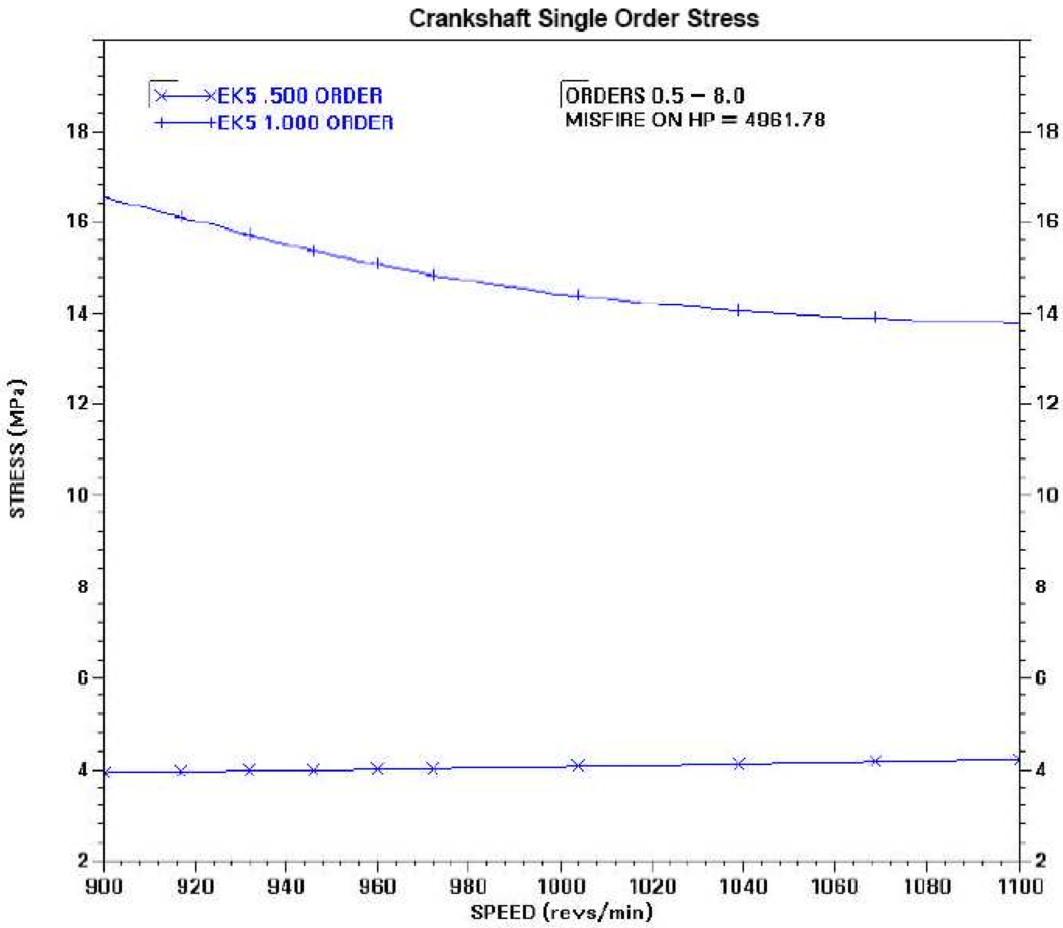

Crankshaft and Generator Combined Order Stress
EK5 MAX SUM OF ORDERS
EK5 MIN SUM OF ORDERS
EK5 SS COMP. OF SUMS
GK1 MAX SUM OF ORDERS
GK1 MIN SUM OF ORDERS
GK1 SS COMP. OF SUMS
ORDERS 0.0 – 8.0
MISFIRE OFF HP = 4961.78
STRESS (MPa)
SPEED (revs/min)

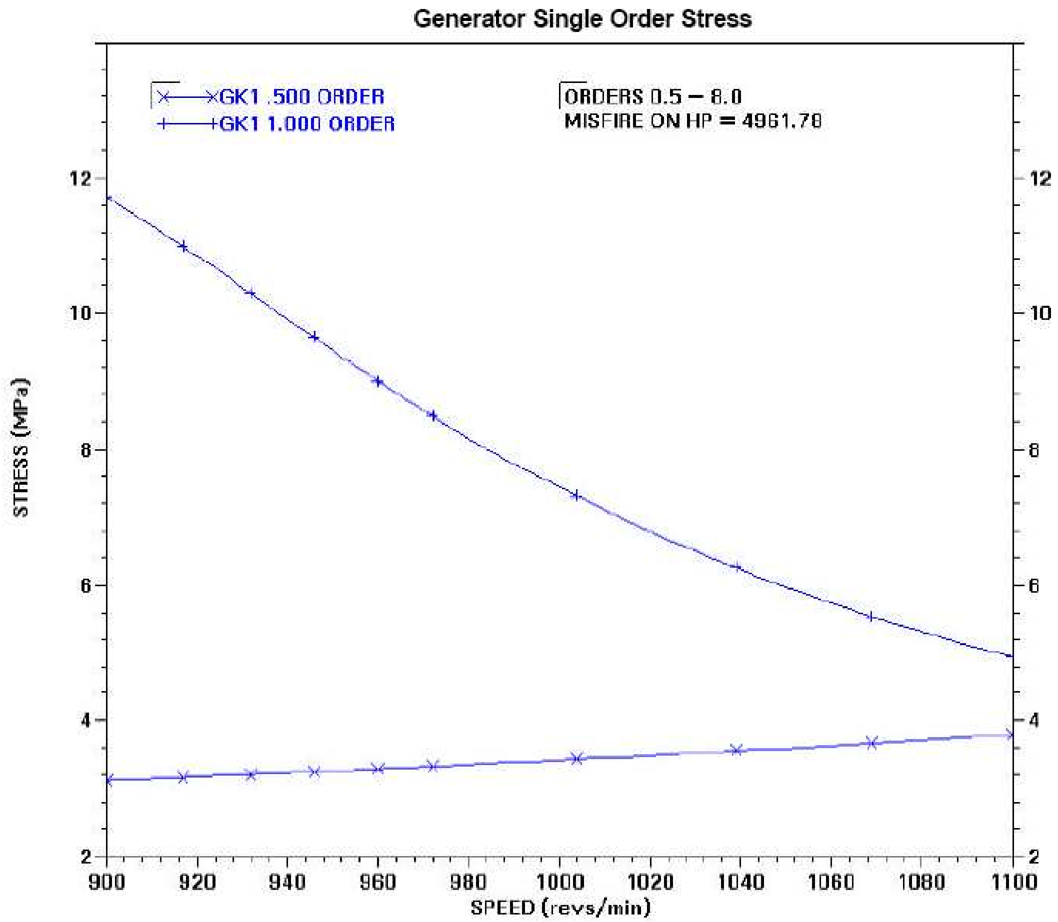

Coupling Combined Order Torque
CPK MAX SUM OF ORDERS
CPK MIN SUM OF ORDERS
CPK SS COMP. OF SUMS
ORDERS 0.0 – 8.0
MISFIRE OFF HP = 4961.78
SPRING TORQUE (N*m)
SPEED (revs/min)


Coupling Combined Order Power Loss
CPK MAX SUM OF ORDERS
ORDERS 0.0 – 8.0
MISFIRE OFF HP = 4981.78
RUBBER COUPLING POWER LOSS (kW)
SPEED (revs/min)
0.132
0.134
0.136
0.138
0.14
0.142
0.144
0.146
0.148
0.15
0.152
0.154
0.156
900
920
940
960
980
1000
1020
1040
1060
1080
1100

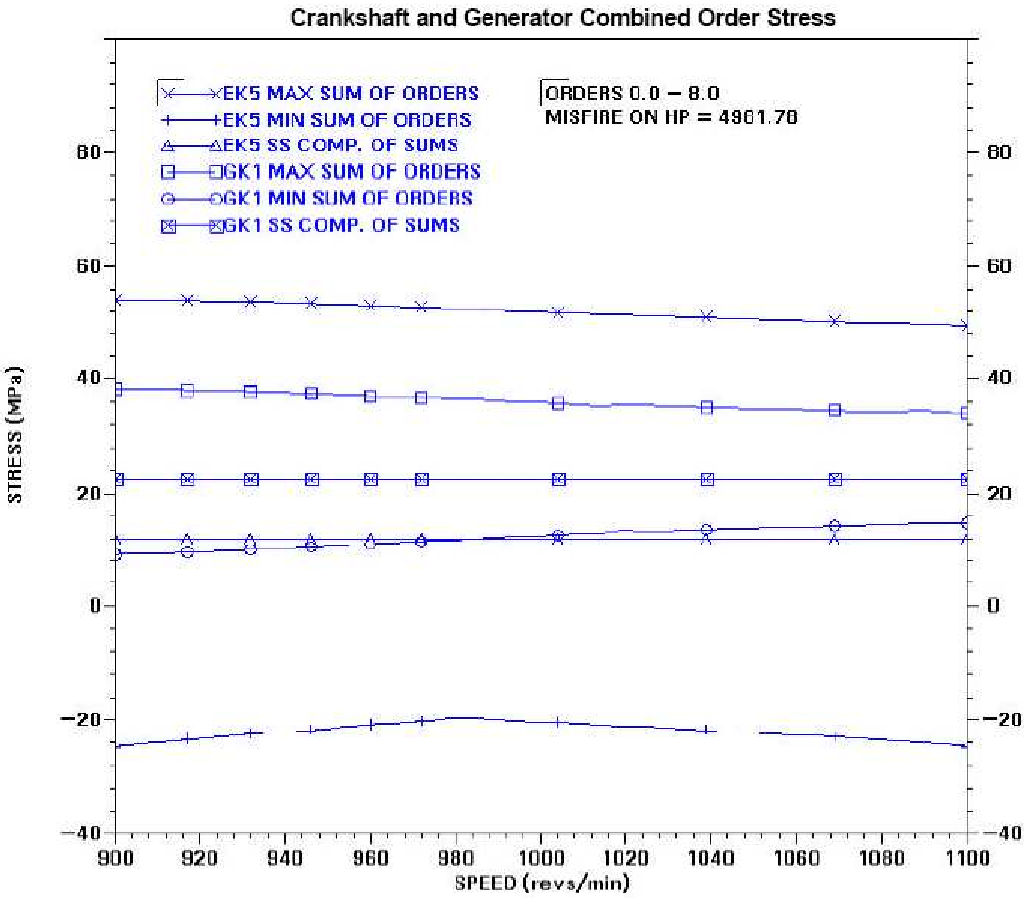

Damper Combined Order Thermal Loading
VD K= 2.85 MN-M/RAD C=7000
ORDERS 0.5 - 8.0
MISFIRE ON HP = 4961.78
POWER PER AREA (kW/m^2)
SPEED (revs/min)

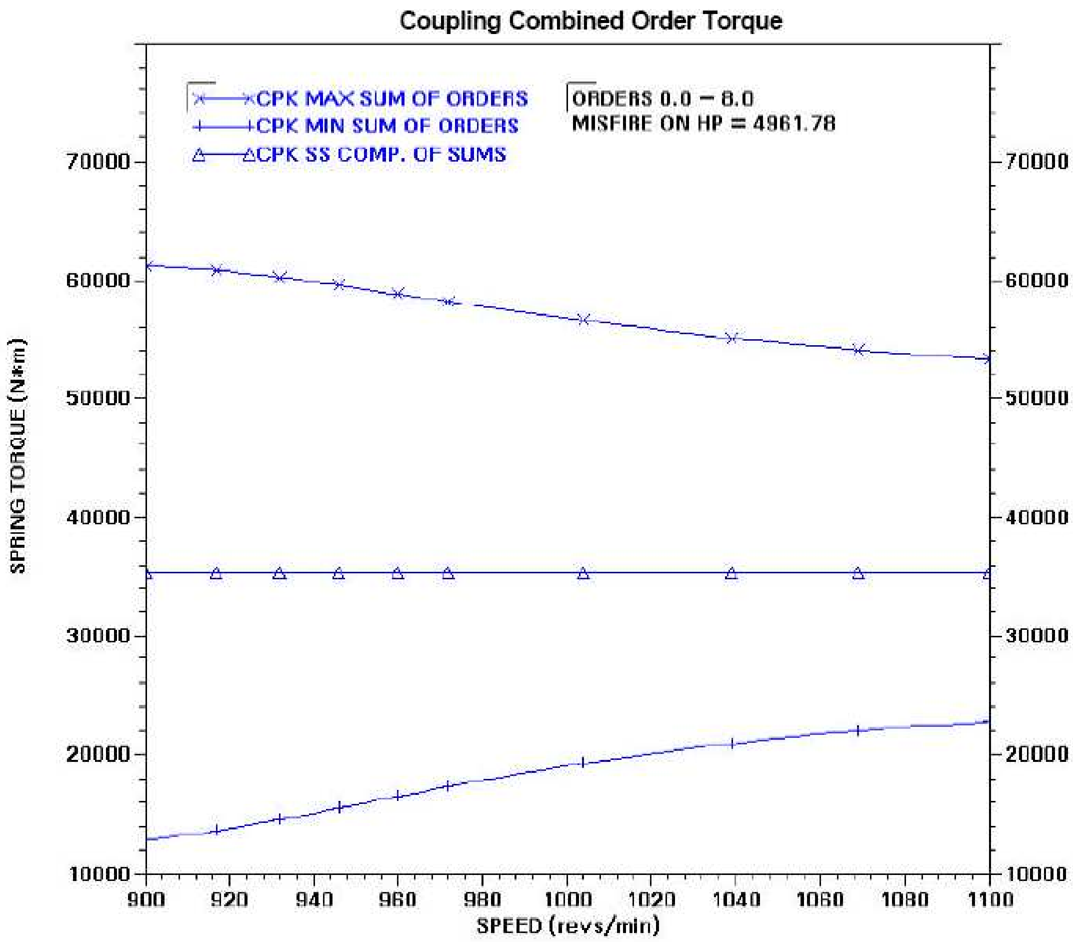

Front Crank Single Order Amplitude
FRT,B ORD # .5
FRT,B ORD # 1.0
ORDERS 0.5 – 8.0
MISFIRE ON HP = 4961.78
ABSOLUTE AMPLITUDE (degrees)
SPEED (revs/min)
0
0.1
0.2
0.3
0.4
0.5
900
920
940
960
980
1000
1020
1040
1060
1080
1100

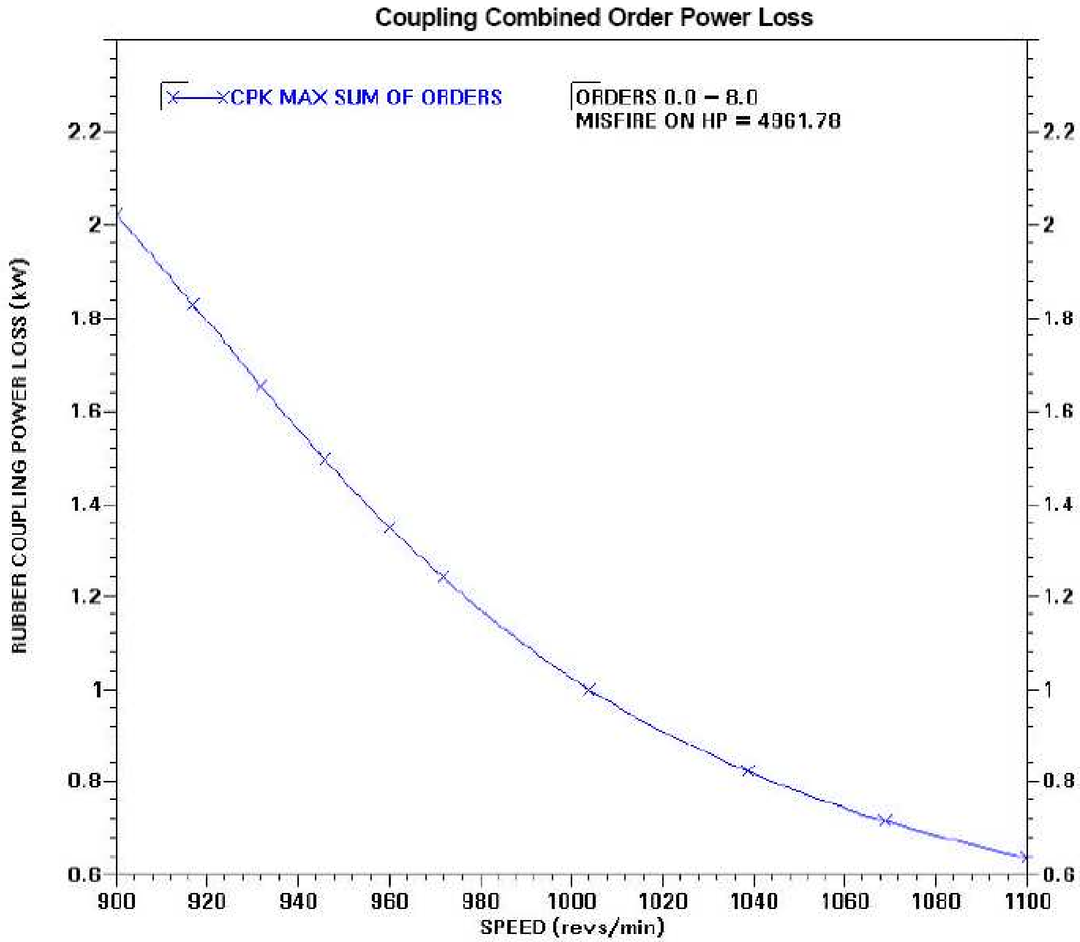

Crankshaft Single Order Stress
EK5 .500 ORDER
EK5 1.000 ORDER
ORDERS 0.5 – 8.0
MISFIRE ON HP = 4961.78
STRESS (MPa)
SPEED (revs/min)
900
920
940
960
980
1000
1020
1040
1060
1080
1100
2
4
6
8
10
12
14
16
18



Generator Single Order Stress
GK1 .500 ORDER
GK1 1.000 ORDER
ORDERS 0.5 – 8.0
MISFIRE ON HP = 4961.78
STRESS (MPa)
SPEED (revs/min)


Crankshaft and Generator Combined Order Stress
EK5 MAX SUM OF ORDERS
EK5 MIN SUM OF ORDERS
EK5 SS COMP. OF SUMS
GK1 MAX SUM OF ORDERS
GK1 MIN SUM OF ORDERS
GK1 SS COMP. OF SUMS
ORDERS 0.0 – 8.0
MISFIRE ON HP = 4981.78
STRESS (MPa)
SPEED (revs/min)
80
60
40
20
0
−20
−40
900
920
940
960
980
1000
1020
1040
1060
1080
1100


Coupling Combined Order Torque
CPK MAX SUM OF ORDERS
CPK MIN SUM OF ORDERS
CPK SS COMP. OF SUMS
ORDERS 0.0 – 8.0
MISFIRE ON HP = 4961.78
SPRING TORQUE (N*m)
SPEED (revs/min)
10000
20000
30000
40000
50000
60000
70000
900
920
940
960
980
1000
1020
1040
1060
1080
1100


Coupling Combined Order Power Loss
CPK MAX SUM OF ORDERS
ORDERS 0.0 – 8.0
MISFIRE ON HP = 4961.78
RUBBER COUPLING POWER LOSS (kW)
SPEED (revs/min)
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
900
920
940
960
980
1000
1020
1040
1060
1080
1100

7 Planos

Plano 1 : Central (planta sin grupos)

Plano 2 : Central (planta con grupos)

Plano 3 : Central (alzado exterior)

Plano 4 : Grupo electrógeno

Plano 5 : Silenciador

Plano 6 : Alternador

Plano 7 : Generatriz

Plano 8 : Estructura soporte grupo

Plano 9 : Cargas estáticas y dinámicas

Plano 10 : Sistema de refrigeración

Plano 11 : Conjunto tuberías

Plano 12 : Depósito de aceite

Plano 13 : Depósito de gasolina

Plano 14 : Esquema hidráulico