6. GENERAL SOLUTIONS

The following are some general rules and advices that should always be fulfilled to assure a correct dynamic behaviour of a PCB in a vibration enviroment. They involve simple but essential measures that must be considered from early stages of design, usually aiming to rise the resonant frequency of the PCB. It is of course possible that they come into conflict with the electronic functionality or any other kind of specification. It is up to the designer to decide which aspect to prioritize in any moment.

6.1 SITUATION OF THE ELEMENTS ON THE PCB

The specific placement of the different electronic components on the board should be planned with the aim of increasing the reliability of the most critical ones, placing them where the minimum deformation is expected.

It is then necessary to know the shape of the most probable deformation of the PCB, which is usually the first resonance mode. Only when it is expected to excite more than one mode a deeper analysis will be necessary. In both cases the electronic compoment must be place according to its characteristics.

As said, the effect of the electronic components on the dynamic properties and behaviour of the board will be neglected. Then the different vibrations modes of the board and the defformation they produce can be easily estimated using shell theory or a simple FEM analysis. It is the defformation associated to the first modes of vibration (usually just one) which is interesting to map, in order to locate the different electronic components in their most convinient place. Small elements, specially legged ones, will be less likely to be affected by vibration, so they are to be placed in the area of maximum defformation, usually the centre of the board. More critical elements, such as big legged components or, specially, BGA components, should be placed where the defformation is expected to be small.

It is important to state that the term deformation does not refer to total displacement of the board, but to the relative deflection between the PCB and the electronic component. It is minimized when the curvature of the board is zero, keeping then its alignment with the component. It would be then necessary to obtain the areas in which the board keep straight, that is, when the flexure moment is zero. This is not the usual procedure, since in most cases critical electronic components are simply placed near the clamped edges. Although not the optimum configuration, this is usually safe enough for most electronic structures. More info for the case in which a more detailed analysis is necessary can be found in RELATIVE DEFLECTION AND BOUNDARY CONDITIONS.

If the electronic component is not symmetric it will also be important that its orientation in the board is studied to avoid defformation. It is impossible to obtain a single rule for how to do it, since there is dependence on several factors such as the boundary conditions of the PCB or the mouning system used, but a simple analysis and common sense will be enough in most cases.

Example

If both a PCB and the electronic component are rectangular, and the board is clamped in the four sides, the best option is to mount the component parallel to the long edge of the PCB, since the relative motion between them is therefore reduced, as it can be seen in Fig. 6.1. The total displacement of the center of the board will be the same for both configurations, but the slope in each direction will be different.

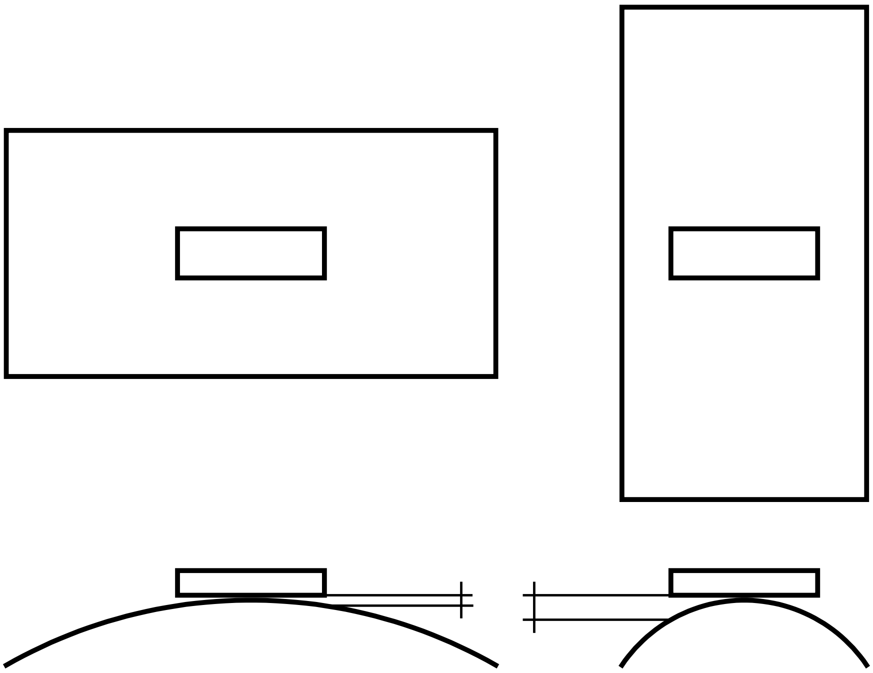

Fig. 6.1.- Relative deflection between PCB and electronic component.

Example

Now the same case as above is considered, but only the two smaller sides of the PCB are campled, and the other two are free. Then it would be more interesting to place the component parallel to the campled edges, since in the first mode of vibration all the lines which are parallel to them will keep undeformed, as seen in Fig. 6.2.

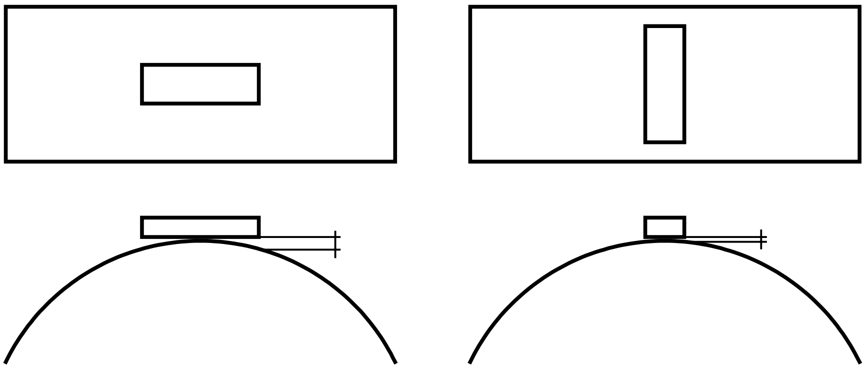

Fig. 6.2.- Relative deflection between PCB and electronic component.

6.2 SIZE OF THE BOARD

Although there are usually strong design restrictions in this aspect, usually because of the shape of the whole machine or tool, there is maybe some small freedom for the designer to decide which the dimensions of the board will be. Assuming an approximately constant surface (so the same amount of electronic components can be placed on the board), it is suggested to choose the size of the board that produces a higher first eigenfrequency.

Example

Three different configurations for a FR-4 board with 6 mm of thickness and 144 mm^2 of surface clamped in both edges and free in the other two will be considered and their five first resonance frequencies compared. No additional mass is used to simulate the effect of the electronic components, since the values, although not the actual ones, are equally indicative.

Resonance frequencies (Hz) 12 x 12 mm square board
377.51
385.71
574.53
1036.8
1051.1

Resonance frequencies (Hz) 18 x 8 mm board clamped in the 8 mm edge
167.59
183.42
460.75
485.99
891.81

Resonance frequencies (Hz) 18 x 8 mm board clamped in the 18 mm edge
848.01
852.52
892.69
1029.7
1334.4

Table 6-1.- Resonance frequencies for different configurations

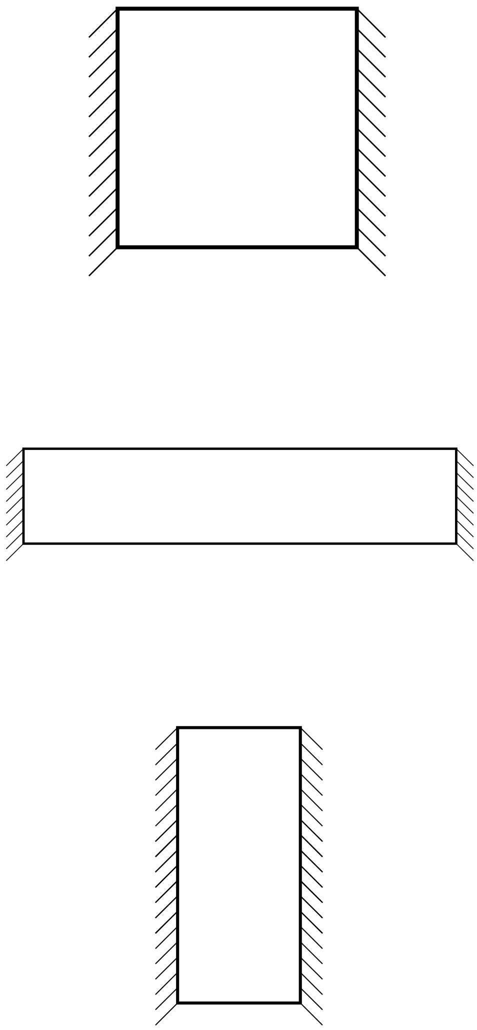

Fig. 6.3.- Different configurations of PCB

6.3 BOUNDARY CONDITIONS

As with the previous measures, the main goal is often to achieve the highest values of eigenfrequencies possible in the board, which as far as boundary conditions are concerned is usually obtained through campled conditions.

It is important to remember, however, that the aim of the design is not to minize the total deflection of the PCB, but the relative motion with the electronic components. Therefore in some cases it might be interesting to consider other configurations appart from clamping all edges. More information can be found in **¡Error! No se encuentra el origen de la referencia.**.

It is important to experimentally confirm that the boundary conditions are the expected, checking if the the edges are translating or rotating. It must be noted that sometimes edge conditions can change during service, depending on the value of the input acceleration forces. During vibration tests edge guides designed to act as simply supported can gradually allow some translation until they appear to be free as the acceleration forces increases. If boundary conditions are not working as expected the effect on the dynamic properties of the PCB can be surprisingly noticeably, as can be seen in the following section.

6.4 LOOSE PCB GUIDES

Plug-in PCBs must have guides designed to fix the side edges, in order to control both the position and the alingment. Since some of the manufacturing process can produce loose guides, it is important to be aware of their effect on the dynamics of the PCB.

Although it may appear that a loose PCB side edge might act like an isolation system, reducing the acceleration leves transferred from the chassis, experimental data shows that the effect is quite the opposite, increasing the acceleration transferred and reducing the resonant frequency.

The first effect is not crearly quantified, but increaments of up to the 20 % of the transmissibility are to be expected.

An estimation of the decrease in resonant frequency can be done considering the PCB to be a mass vibrating between two springs with a clearance distance a between the mass and each of them, as seen in figure Fig. 6.4. The springs represent the defformation of the PCB, so now its complete cycle during vibration will consist on both translation and defformation. The new eigen frequency is equal to the inverse of the period, that is, the time consumed during the whole cycle.

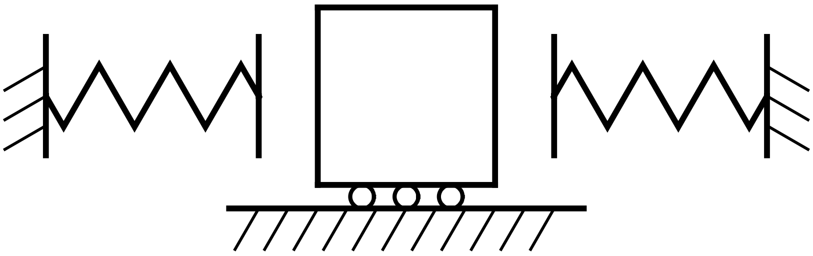

Fig. 6.4.- Model for loose guides.

The period of the whole cycle will be considered as the sum of the time consumed in the translation and the period of the defformation-vibration, which will be assumed to be harmonic vibration. Both movements will be considered independent, which is not true but will provide an approximation which is accurate enough.

The period of the defformation cycle is, according to the new model, equal to

$$P_1 = 2\,\pi\sqrt{\frac{M}{K}} \tag{6-1}$$

where M and K are the mass and spring costant. It is possible to obtain the equivalent mass-spring model of the defformation of a PCB, with expressions that can be found in any mechanical engineering book. The process is however much more difficult than just obtain the frequency of the PCB with no side clearance and invert it to get the period. This will usually be the method to follow.

For the translation part it is first necessary to find the velocity of the PCB, since the period will be equal to the space covered divided by the velocity, that is,

$$P_2 = \frac{4\,a}{v} \tag{6-2}$$

According to the assumption that both movements are independent, the speed of the board-mass at the start of the translation will be equal to the maximum speed during the vibration-deformation, that is,

$$v_{max} = \Omega \; x_{max} \tag{6-3}$$

where x_{max} is the maximum displacement during the vibration-deformation, whose equation therefore is

$$x = x_{max} \sin \Omega\, t \tag{6-4}$$

Total period would then be

$$P = 2\,\pi\sqrt{\frac{M}{K}} + \frac{4\,a}{\Omega\, x_{max}} \tag{6-5}$$

Ω and x_{max} can, as usually, be obtained experimentally, extrapolated from similar experimental data or estimated using the same expressions as before.

$$P_2 = \frac{4\,\delta}{\Omega\, x_{max}} = \frac{8\,\pi\,\delta\,f}{a_{max}} = \frac{8\,\pi\,\delta\,f}{a_{max,input}\; Q} \qquad (6\text{-}6)$$

If the transmissibility Q is not known one of the approximations from [1], for example $Q = 1.2\sqrt{f}$, and the resulting equation would be

$$P_2 = \frac{20\,\pi\,\delta\,\sqrt{f}}{3\,a_{max,input}} \qquad (6\text{-}7)$$

Some examples are given to show the effect of a little clearance on the natural frequency of the PCB.

Example

A PCB has a resonant frequency of 200 Hz when clamped in two of its edges, but in the real conditions one of them has a clearance of 0.25 mm. Assuming the approximation $Q = 1.2\sqrt{f}$ is useful, and an excitation level of 6 G, the actual resonant frequency of the PCB is

$$P = P_1 + P_2$$

$$P_1 = \frac{1}{f_1} = \frac{1}{200} = 0.005\ \text{s}$$

$$P_2 = \frac{20\,\pi\,\delta\,\sqrt{f}}{3\,a_{max,input}} = \frac{20\,\pi\,0.00025\,\sqrt{200}}{3\cdot 6\cdot 9.8} = 0.0013\ \text{s}$$

$$f = \frac{1}{P} = \frac{1}{P_1 + P_2} = 158.73\ \text{Hz}$$

The clearance, while small, produces a noticeable reduction of the resonant frequency of the board.

6.5 OCTAVE RULE

It is difficult to determine when the resonant frequency of an electronic system will be high enough to assure its reliability. However according to experience vibration failures are often avoided or at least reduced by using the octave rule. This rule considers a vibrating structure to be a combination of different masses interconnected by springs, representing the stiffness of the structure, as seen in MULTYBODY

SYSTEMS. Each spring-mass pair is then a degree of freedom with its own natural frequency.

The rule states that each of theses resonance frequencies should be at least twice of the preceding one in the system, that is, the frequency should be doubled every time an additional degree of freedom is added to the system. This way the possible combination of resonance conditions of different parts of the system is avoided. Instead, when one of them is on resonance, the natural attenuation of the rest is acting, reducing the final response of the global system.

Despite its extreme simplicity, the octave rule is considered one of the most effective tools to improve reliability of electronic structures. It is most suited for the typical case of a plug-in PCB and an electronic box. It is then essential to assure that the resonance frequencies of both bodies are different enough to avoid combined amplification of the excitation. Its application is probably more difficult in the case of PCBs rigidly connected to the source of excitation, that is, without any intermediate susbsytem, for example in hand tools. Even this way the rule could be used a useful guidance for the evaluation of the resonant frequency of the system. For instance, it is interesting to achieve the same frequency distance with the excitation expected.