Don’t confuse **RESONANCE** with **INSTABILITY** of cage in ball bearings!

Resonance = cage instability?

Mystification of the senses

Cage instability is a very particular phenomenon, often overlooked and encountered in many mechanical applications.

However, when it occurs, the user of ball bearings does not realize what is happening: he hears a shrill noise and measures vibrations, all appearing suddenly. No doubt: if it vibrates, that is because of resonance! Without delay, he confronts his intuition with reality and initiates a vibration analysis to confirm his certainties. The characteristic frequencies of the bearing (fundamental train frequency, ball pass frequency on both rings, ball spin frequency, etc.) are not visible in the measured spectrum. However, remarkable peaks are clearly present, at rather high frequencies. All this should confirm that a resonance phenomenon is present! Unfortunately, the natural frequencies of the mechanical system do not appear in the spectrogram.

And yet, it vibrates! Even more: it looks like it really comes from the bearing! But to what can he connect these elusive facts? What did he omit from the inventory of probable causes?

Answer: the bearing cage! Indeed, his accelerometers tell him that a peak appears at a frequency several dozen times higher than that of the rotation of the bearing. In addition, a few secondary peaks arise around the main peak. And, above all, the gap between the peaks corresponds to the self rotational speed of the cage. In other words, the phenomenon is modulated by the characteristic frequency of the separator. So there is no longer any doubt: the bearing user is in the presence of a potentially dramatic resonance of the cage.

If the cage is indeed the source of the problems, it is not a question of *resonance* but of cage *instability*.

An explainable confusion

In order to understand where the confusion comes from, it is appropriate to focus on the very nature of the two physical phenomena at play.

Let's start with resonance. Let us consider the free oscillations of a mass connected to a spring (Fig. 1). Its total energy is calculated by the simple addition of its potential energy, coming from the compression or extension of the spring, and its kinetic energy, which is exclusively due to the speed acquired by the suspended mass. Thus, the oscillations of this mass are only the reflection of an uninterrupted exchange of energy: when the spring is compressed or stretched to its maximum level, the speed of the mass is zero; conversely, the speed is maximum when the length of the spring is natural.

Resonance appears when the total energy increases exponentially over time instead of plateauing at a constant level (Fig. 2). This occurs when an excitation force perfectly in phase with the speed of the free oscillations of the spring is applied. A point of attention should be noted: only the frequency of this load matters, its amplitude being completely secondary.

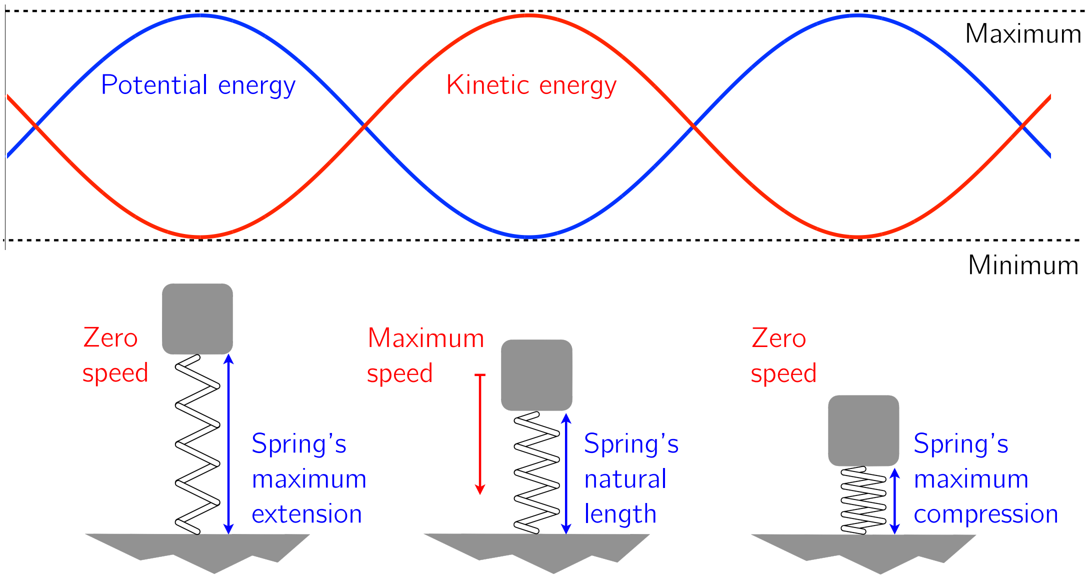

Fig. 1 – Free oscillations of a spring/mass system

What about cage instability? The impacts generated by the free movement of the cage within the bearing are of relatively random frequency and intensity. At least, when the cage is not unstable. As soon as the cage becomes unstable, a high frequency whirling motion predominates. This fairly sharp frequency is very visible on experimental measurements, as are its harmonics, whether on torque measurements or *via* accelerometers. This only ever constitutes the image of the interactions of the cage with the rest of the bearing elements.

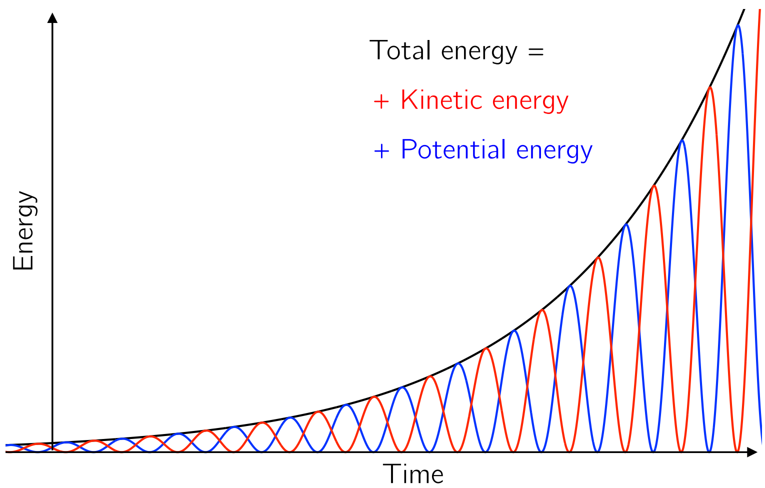

Fig. 2 – Increase in energy in case of resonance

Clearly, we see that impact efforts have a certain periodicity. However, the appearance of periodic high-frequency stresses, which are exclusively generated by the cage instability mechanism, looks pretty much like an entry into resonance...

Like the resonance phenomenon, a cage instability occurs when the total energy of the system increases according to an exponential law. That being said, the fundamental difference is that the kinetic energy merges with the total energy, without noting the slightest exchange between the two forms explained in the case of the suspended mass (Fig. 3). Unlike resonance, this uninterrupted increase in kinetic energy goes hand in hand with the amplification of stresses. Indeed, an ordered movement takes place: the impact forces acting on the cage increase both in amplitude and frequency.

Resonance as a consequence of cage instability

Thus, the instability comes from the capacity of the cage to constantly increase its kinetic energy, to accumulate the energy transmitted by the rotation of the ball bearing. The absence of exchanges between potential and kinetic energies in the unstable phase entry mechanism therefore excludes structural deformations of the cage as a necessary condition for the appearance of any instability. In other words, the possibility of moving freely as a rigid body between the balls and the rings happens to be the essential prerequisite for any start of instability.

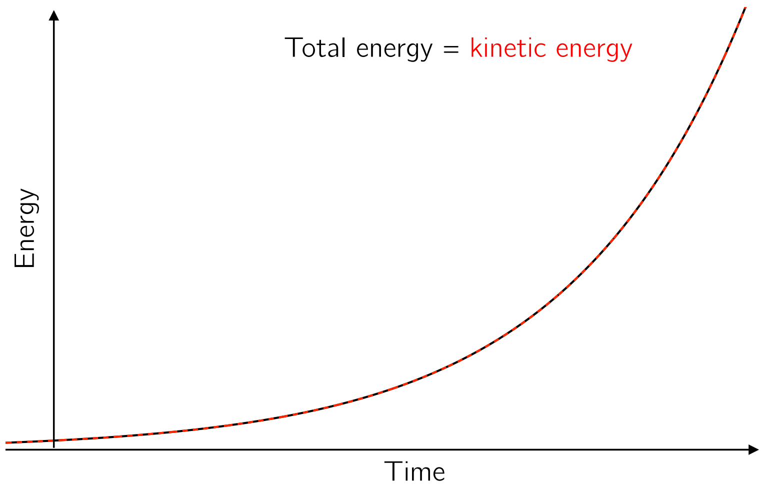

Fig. 3 – Increase in energy in case of instability

However, it should be noted that the high frequencies and the cyclical nature of the forces arising following cage instability can induce other deleterious phenomena. Among which... resonance! Indeed, if these unwanted frequencies were to coincide with one of the natural frequencies of the assembly, or even of the cage itself, then other sources of vibration could be feared.

Cage instability can cause resonance. But the converse is false.

Christophe Servais, Ir, PhD
Chief Technical Officer

cse@apo-gee.tech
www.apo-gee.tech