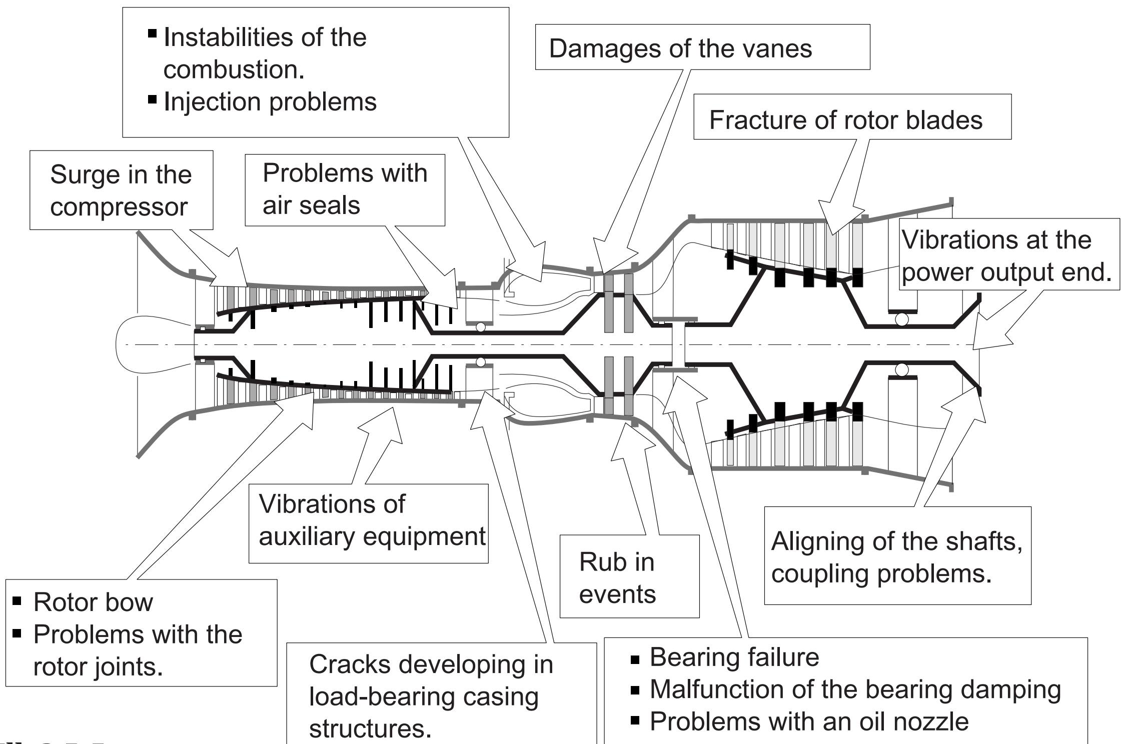
There are many reasons for vibrations. The analysis of oscillations permits conclusions on the causes and looming damages.




**Ill. 2.5-5**

***Ill. 2.5-5:*** *In this illustration, typical causes for unusual heavy **vibrations of a gas turbine** are collected.*

***Oscillations in the combustion chambers*** *(combustion instabilities, Ill. 3.2.2-5): They normally vibrate with the relatively low frequency (‘**buzz**’) of the gas stream during the combustion. Those vibrations should be considered and mastered by the designer. However it’s possible that due to **water or steam injection** (Ill. 3.2.2-4) or problems with the fuel injection, abnormal high vibrations occur. Especially frequent oscillations are observed at **Dry-Low-Nox combustion chambers** which operate with a very lean fuel/air mixture. Even gas from an other source can stimulate instabilities.*
*The pre mixing with a large quantity of air favors such a **self amplifying instability of the combustion** (Ill. 3.2.2-5). Those violent vibrations, e.g. can lead to unexpected heavy abrasive wear (fretting) of the assembly connections and the break away of chamber shingles (Ill. 3.2.1-4).*

***Surge in the compressor*** *can in the formation phase (eg. rotating stall, Ill. 3.1.1-5) trigger vibrations and fatigue failures of blades and vanes. A complete stall of all blades (surge) with the disruption of the air stream leads to heavy abrupt impulses with the threat of a short-term* *dynamic overload of the blading and/or intense rub (Ill 3.1.1-6). Not dissipated friction heat with the air ('blunger loss') in the momentary lack of an air stream can short-term overheat and damage the rotor blades. The lack of cooling air in the hot parts, together with a shortage of combustion air, can lead in very short time to grave overheating damages.*

***Rotor bow** and **rub events**: The differentthermal inertia of the rotor and the casings, even hours in the cooling phase can lead to gap bridging and jam of the rotor (Ill. 2.2-2 and Ill. 3.1.2.4-2). The warm air in the shut down, standing still engine rises up and heats the upper part of the rotor more intensive than the zones beneath. The consequences are self reinforcing vibrations in the frequency of the rotor speed with dangerous damages. This includes the weakening of the rotor by abrasive wear and the overheating as well as overloading the blading.*

***Air seals**: Vibrations of labyrinths can be excited in manifold ways. Examples are excitations by the leakage stream or gas oscillations in the ring chambers around the rotor shaft, formed by the seals. The results can be fatigue cracks and break-outs (plate vibrations) at thin walled components. Endangered are e.g., baffles or support cones of the labyrinths.*

***Casings:** The stiffness of supporting casing structures can change as result of a **crack formation**. Normally this leads to the weakening of the cross section with a **drop in the natural frequency**. That permits increased vibrations (example 2.5-2), especially in case of resonance. Corresponding with the crack growth, normally the vibration level rises with the operation time.*

***Turbine vanes**, **turbine nozzles**: Damages of the turbine nozzles (high pressure turbine entrance vanes) can excite the rotor via the blades to vibrations that also show outside the engine.*

***Turbine rotor blades**: In the turbine the breaking of a blade can quite happen, especially if only a part of the blade which is not at once noticed, is concerned. On the other hand in a compressor substantial secondary failures can be expected when a blade breaks. This means the immediately breakdown of the engine (example 2.5-2).*
*Smaller turbine defects can be recognized by the unbalances. This is not easy when the engine has elasic suspended, damped main bearings. We find such a design in aero engine derivates. In this case the unbalance forces are only little noticeable at the acceleration probes on the outside of the engine. Heavy damages can be expected from an operation over longer time with internal unbalances. Therefore it is important that the **trigger intensity settings** of the **probes** are satisfactory sensitive without activation of false alarm.*

***Main bearings:***
***Anti friction bearings** (chapter 3.5.2.1)**:** Failures cause remarkable, mostly high frequency **vibrations**. There are failures which show early enough before a catastrophic vibration. To this belong fatigue outbreaks (fatigue pittings, pittings) in the bearing races. Is there the suspicion of a bearing failure, **magnet plugs** and **oil filters** must be controlled. On the other hand, in case of indications at a magnet plug, a very close look for vibrations is recommended (Ill. 5.1-1).*
*There is quite a realistic chance to **recognize** at big engines a bearing failure **in time** with a relatively low number of rotation. In contrast **smaller engines with higher speed** sustain catastrophic bearing failures in short time. **Small gas turbines** may suffer this **in seconds** during the observable end phase. Comprehensible, an engagement to capture such a failure in time is hardly possible.*
*An intermittent oil supply can also provoke vibrations in the bearing area. Thereby also*

exists the danger of the breaking of the oil jet with extensive second failures.

**Friction bearings/journal bearings** (chapter 3.5.2.2): In gas turbines of the heavy type, normally journal bearings are used. They have specific failure modes (Lit. 2-10 und Lit 2-11). Typical causes of damage are:

- **Production failures** of the babbitt (sliding layer/ sliding material).
- **Contaminations** from the production e.g. (machining chips), overhaul (eg., blasting abrasives), unsatisfactory maintenance (problems with the cleanness) and damages in the oil system (e.g., bearing or gear failures). They are washed in by the oil.
- **Abrasion** by mixed friction.This happens from lubrication problems (e.g,. the oil supply, over load or tilting).
- **Over load** of the babbitt leads to local plastic deformation (creep). Causes are too high contact pressure in connection with the operating temperature.
- **Dynamic fatigue** (fatigue cracks in the babbitt, 'paving stone' break-outs) by pressure pulsation in the lubrication gap.
- **Cavitation** leads to small break-outs by vibration fatigue of the babbitt. This is favored by water in the oil (vapor bubble formation) and entrained air.
- **Chemical attack** develops by corrosion and/or reactions of the babbitt with the oil (e.g., with aggressively deterioration products).
- **Electro erosion/electric discharge erosion** from an electric current.

**Accessory equipment** (chapter 3.6.1) can be excited to vibrations by the failure of components like **gears** (chapter 3.7-2), **couplings/insert shafts** (Ill. 3.6.1-7) or **bearings** (chapter 3.5-2). In an extreme case this leads to the fracture of the mounts and/or destruction of the device. It is also possible that vibrations are routed into the engine and produce damages. So, e.g., a case emerged, at which a small **inaccuracy of a gear wheel** lead to the **fatigue fracture of the central interlocking bolt** of the turbine rotor. Emanating from the teeth of gear wheels are extremely high frequent vibrations (up to the ultrasonic region) because the number of teeth and the high rotation speed. At the arising vibration modes even smallest amplitudes in the region of 0.1 mm are enough for a damage by vibration fatigue.
Subsequent installed accessory drives with alternating torsion moment like **cardan shafts** or universal couplings with **elastomers** can excite vibrations through a gear in the engine and produce failures. In such a case it came several times to the fracture of a drive shaft in a control unit which was driven by a **gear**. This potential transmission of vibrations could easily be overlooked. It was therefore discovered not until several failures.

**Vibrations of the drive train**: **Insufficient aligned shafts** and **couplings** can trigger vibrations. The neccessity to drive through resonances has the risk of high amplitudes with an **over load of the schaft up to a fracture**. Also vibrations of the powered aggregates (e.g., pump or generator) can be fed into the engine by couplings. Are vibrations of the rotor excited, an increased damage hazard exists. Therefore special regard to the **correct funktion of the drive side** is needed.