7.1.2.2 Rotor bow

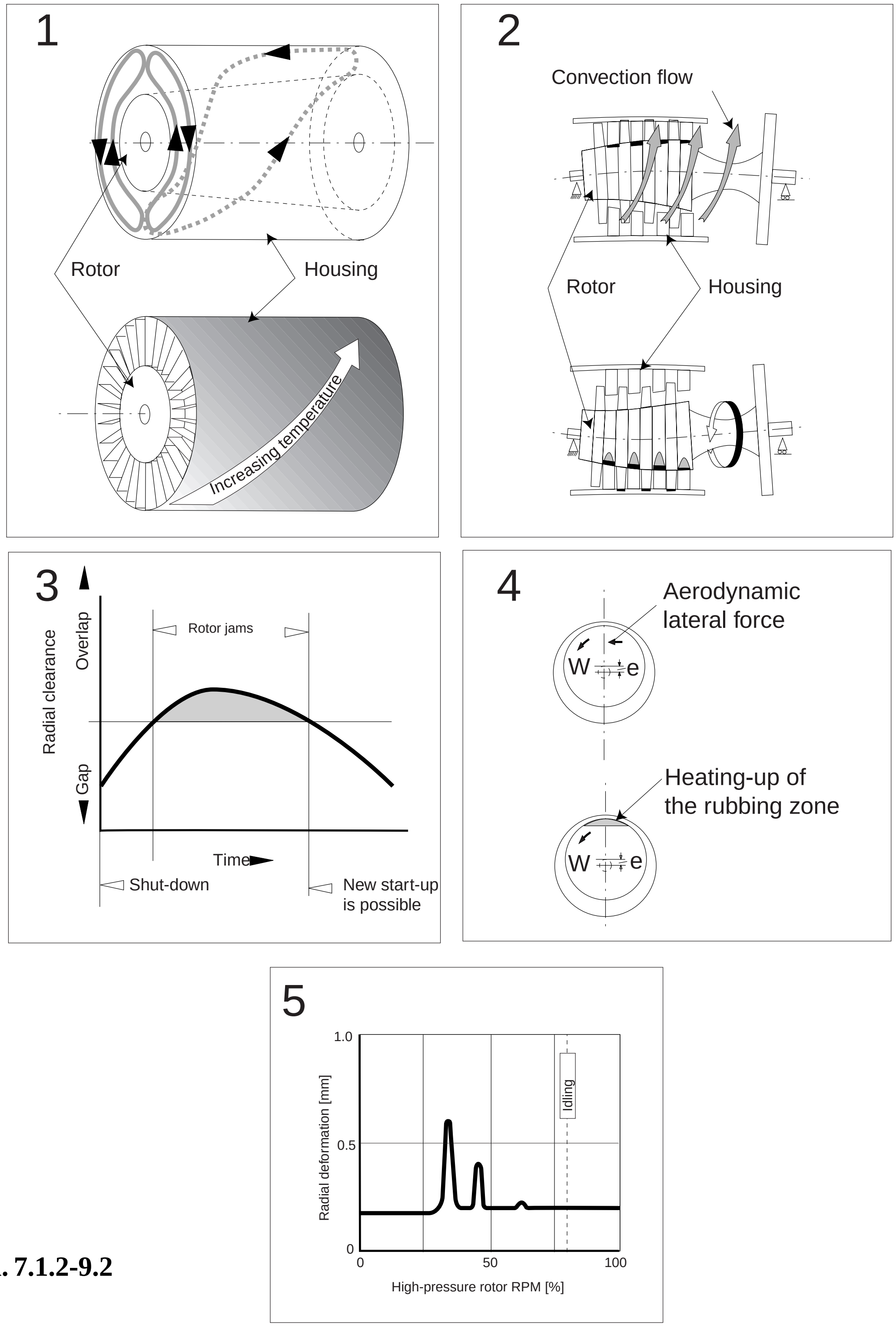
Uneven cooling along the circumference of long compressor rotors, especially drum rotors, can cause rotor bow and large imbalances during start-up if the engine has not cooled down sufficiently.

Illustration 7.1.2-9.2 (Refs. 7.1.2-3, 7.1.2-9 and 7.1.2-19): *After an engine is shut down, the air inside heats up on the warm engine parts and rises. There it cools against the housing and sinks back down into the lower compressor zone. This creates a circular flow around the rotor (top left diagram). The back, warmer part of a compressor gives this flow an axial component. The combustion chamber also affects this, although its mass is not very large. The warm air causes the top part of the rotor hub to cool slower than the lower part. This causes radial temperature gradients and* **thermal rotor bow.** *The rotor bows at the top as the result of the top part expanding as the bottom contracts. High-pressure compressors with large axial length are especially susceptible to this phenomenon.* **Rotor bow can permanently change shrink-fits. This results in imbalances remaining even after the engine has cooled completely (Ref. 7.1.2-19)***. There have also been casesin which the low-pressure turbine experienced thermal bow (Example 7.1.2-3). Rotor bow causes large imbalances. These can cause damage by overheating, wear, or dynamic fatigue in parts affected by rubbing, such as blading, housings, or rotor hubs. Even those parts not affected by rubbing, such as bearings and bearing casings or labyrinths, can be seriously damaged (Example 7.1.2-3).*

If ***the rotor hub rubs when the engine is started,*** *it heats up even more at the rubbing point and bow increases (top right diagram) This rubbing process can cause catastrophic destruction of the rotor hub. The engine can only be safely restarted after a sufficiently long cooling period (in hours, depending on the engine; middle left diagram, see also Ill. 7.1.2-8). Sufficient cold clearances result in unproblematic hot start behavior. This is a compromise. The eccentricity of rotor bow with corresponding gap changes around the circumference can cause eccentric aerodynamic forces around the rotor (****"Whirl"****). These increase the eccentricity cause by the imbalances, even if no dangerous rubbing is occurring (middle right diagram). Whirl causes shearing forces that act at roughly 90° to the eccentricity. These forces are due to the increased blade loads and small clearance gaps (low leak flow) compared with blades with large tip clearance around the circumference. During start-up, the radial deflections of the bowed high-pressure rotor occur periodically, depending on the engine type, and are especially large at lower RPM (bottom diagram, Ref. 7.1.2-3). Damped bearings can lessen the oscillations of a bowed rotor. However, the damping must be tuned. For example, in the case of a large fan engine, an 0.2 mm oil film is seen as sufficient. With several minutes of idling operation after start-up and before shut-down, the chances for controlling rotor bow are high. This results in sufficient cooling and temperature distribution without impermissibly high gradiations (Example 7.1.2-3).*

Unlike in steam turbines, there have been no reports of damage to engines caused by housing distortions during standstill. This advantageous behavior is most likely due to the comparatively thin walls of engine housings.

Rotor bow is a phenomenon that can significantly affect practical operation.



Ill. 7.1.2-9.2