SIKO
The Safety Design Concept
Over the past decades the output of diesel and gas engines has been steadily increased, presenting the turbocharger manufacturer with the challenge of continually increasing the compressor pressure ratio. Whereas, in the past, turbochargers could be operated with large design margins, the higher performance required today calls for design solutions which lie much closer to the physical limits of the turbochargers. The load factor for the rotating components in particular has increased dramatically – turbochargers are turning faster and faster.

At the same time, expectations regarding the reliability and safe operation of the equipment have grown considerably.

ABB Turbocharging addresses this issue within its Safety Design Concept ‘SIKO’.

SIKO is a calculation tool for determining the speed and temperature limits of turbocharger rotor components for given exchange intervals. The program is available for the older VTR..4, VTC..4 and RR..1 turbocharger families as well as for today’s TPS, TPL, TPR and A100 series. SIKO is regularly updated to keep it state-of-the-art and will also be implemented for coming ABB turbocharger generations potentially enhanced by digital solutions.

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**SIKO**

The Safety Design Concept

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**01** TPL-B rotor – some key figures

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**02** ABB service engineer
The high rotating speed, for example, has the effect of producing very high kinetic energy inside the turbocharger. Failure of a rotor component often leads to total loss of the turbocharger, and thus costly downtime.

SIKO was created to increase turbocharger reliability, maximise safety and make life cycle costs more predictable by adopting the principle of preventive maintenance instead of 'break and fix'.

The results of the SIKO evaluation, ie. the turbocharger speed and temperature limits as well as the recommended exchange intervals, are given on the rating plate. Operating the turbocharger beyond the specified exchange interval increases the risk of failure.

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01 Turbocharger rating plate
02 ABB Service engineer

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Turbocharger operational limits at engine overload (110%) in test rig operation only.

Turbocharger operational limits in service.

Recommended exchange interval for the compressor wheel.

Recommended exchange interval for the turbine.

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ABB Turbo Systems Ltd

Turbocharger

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SIKO consists of four modules, designed specifically to determine:

1. Load profiles, i.e. turbocharger operating conditions.

2. Material properties.

3. Stress and material temperature distributions.

4. Speed and temperature limits using a damage accumulation method.
1. Turbocharger operating conditions

Knowledge of how the rotor components behave in operation is a key element of SIKO. The load profile for a turbocharger – load versus time and versus the number of load cycles – is not the same, for example, for a container vessel and a locomotive. Similarly, it is different for a base load power plant and a hospital emergency unit. Even with marine applications, the load profiles can be completely different.

ABB designed special data loggers, similar to the ‘black box’ in an aircraft, in order to measure and collect real world turbocharger operation data over an extended period of time, typically four to six months and in some cases up to one year. This measuring device has allowed ABB to determine load profiles for a wide range of engine applications. Over the years, the company has built up a huge database and accumulated a wealth of information and knowledge about the real world operating conditions of turbochargers used in many different engine applications.

The measurements include the turbocharger speed and the temperatures at the compressor and turbine inlets. The two part load profile allows an evaluation of the creep and fatigue loading of the rotor components.
2. Determination of material properties

ABB carried out extensive tests to determine the material properties, i.e. the tensile strength, yield strength, creep strength and fatigue strength. Figure 01 shows the effect on the creep rupture strength of increasing temperature, and Figure 05 the fatigue strength.

The material properties are obtained by means of tests carried out on laboratory specimens. One important aspect of the material properties is the statistical scatter. This is clearly seen, for example, when several specimens with the same geometry are loaded at the same stress level and the same temperature. The time until failure will vary strongly. It is usually necessary to repeat a test at the same stress and temperature level several times in order to obtain statistically significant material properties. Such tests demand special laboratory resources and run for a very long time – a 100,000 hour creep test, for example, lasts all of 11 years.
### 3. Stress and material temperature distribution

Finite element analyses are carried out to obtain the stress and material temperature distribution in the rotor components. These analyses identify the critical locations and determine the local stress and material temperature as a function of the turbocharger speed and the suction air and exhaust gas temperatures.

Stress distribution in the rotor components of a turbocharger varies greatly according to the geometry of the part. Finite element analyses have therefore been carried out for every design of the compressor wheel and turbine. SIKO also takes account of the thermal stress caused by temperature distribution in the component and, in the case of compressor wheels with a center bore, even the pre-stresses induced by spinning during manufacture.

The material temperature strongly influences the material properties, and thus the speed limit and exchange interval for rotor components. In addition, the temperature distribution induces thermal stress in components, as already mentioned. SIKO therefore takes full account of the influence of temperature. Extensive measurements carried out on turbochargers provided the basis for the calculation and calibration of the temperature distributions. The suction air temperature and exhaust gas temperature at the turbine inlet, for example, directly influence the temperature level in the compressor wheel and turbine.
4. Calculating speed and temperature limits using the damage accumulation method

The turbocharger speed and the inlet temperatures are the parameters directly responsible for the loading of rotor components.

When the material properties, the stress distributions and the material temperature distributions are all known, it is possible to determine the speed and temperature limits for the required exchange intervals.

Calculations are performed for every critical location in the compressor wheel and turbine. SIKO makes use of the linear damage accumulation method according to Palmgren-Miner (Figure 01). An accumulated damage value of 1.0 represents the time at which the exchange becomes due. The speed limit for the complete component is determined by the lowest speed limit at one of the critical locations.

The following parameters strongly influence the speed limit and exchange intervals of the rotor components:

- Turbocharger speed profile (speed level and speed cycles)
- Suction air temperature
- Exhaust gas temperature at turbine inlet

Based on the application and ambient conditions, ABB recommends speed and exhaust gas temperature limits as well as exchange intervals for the rotor components, allowing safe and reliable operation from the beginning. This information is given on the rating plate of every delivered turbocharger. In some applications, e.g. where a higher speed limit is required or when the load profile features many more load cycles, certain restrictions may be introduced. These could require, for example, shorter exchange intervals or the use of special materials, such as titanium for the compressor wheel, as a further means of ensuring reliable turbocharger service and avoiding cost intensive downtime of the equipment.