Upgrading a Gear Testing Machine for use in Single Flank Testing and Airborne & Structure-Borne Noise Measurements

July 2000

rotec GmbH, Joseph-Dollinger-Bogen 18, D-80807 München, Germany

Phone: +49 (0) 89 32 36 51 0

Fax: +49 (0) 89 32 36 51 56

Contents

1 - Introduction

The machine in question was primarily designed for contact pattern imaging of gearsets and analysis of airborne sound detected with a microphone (Figs 1 and 2). Both the contact patterns and the sound level are evaluated subjectively by the operator. The rotational speed of the drive side is set to a given speed and the output side is braked manually in order to load the gearset and ensure constant tooth surface contact.

This procedure relies to a large extent on the skill of the operator. To replace this largely subjective and qualitative approach with quantitative testing methods it was decided to modify and upgrade the machine in order to make both single flank testing and the measurement of airborne and structure-borne noise possible. This involved both the introduction of new instrumentation and the mechanical modification of the machine which may be summarised as follows:

- Fitting a magnetic particle brake onto the end of the output shaft to provide constant and reproducible braking moments.
- Incorporating a high-resolution incremental encoder into both the input and output spindles to provide signals for transmission error measurements.
- Positioning a microphone in the vicinity of the gearset for provision of airborne noise signals.
- Adding an accelerometer to the driven side spindle housing for provision of structural noise signals.
- Employing a **rotec**-RAS measurement and analysis system for high-resolution, synchronous acquisition of the incremental encoder, microphone and accelerometer signals, documenting the braking moments, data analysis and protocolling results.

Figure 1 The gear testing machine before any modifications were carried out.

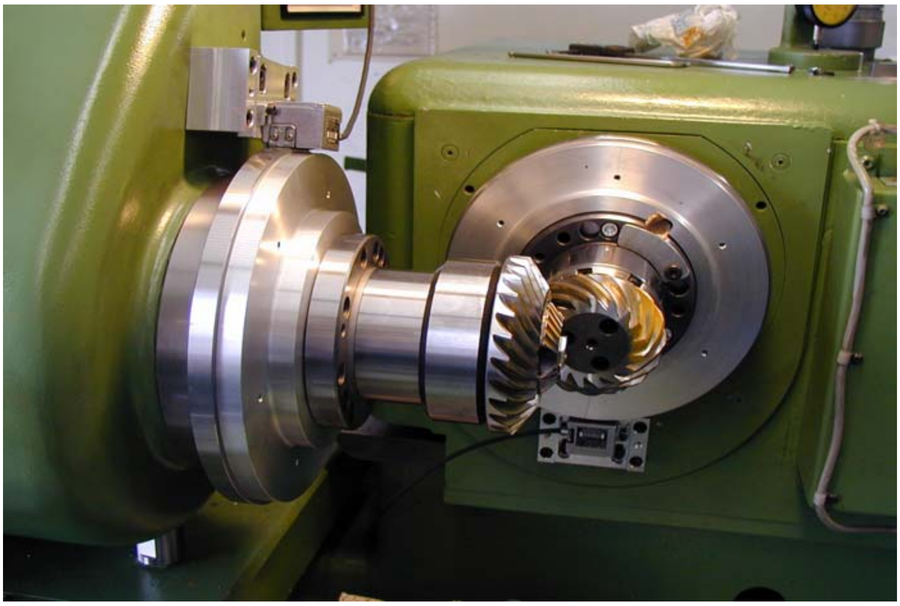

Figure 2 Close-up of a gearset showing the location of the rotary incremental encoders as well as contact image patterns on the tooth surfaces.

2 - Gear Noise and Transmission Error

Gear noise is a major concern in the design and manufacture of gearsets. A pair of gears should transfer angular motion uniformly and the Transmission Error is defined as the difference between the actual position of the driven gear and the position it would occupy if the gearset were perfectly conjugate. It is generally accepted that Transmission Error is the main cause of gear noise.

2.1 - Single Flank Testing

The Single Flank Test is a two-channel rotational speed measurement. The measurement is performed by integrating high-resolution rotary encoders into the shafts of the driving and driven gear wheels (pinion and gear). By definition, single flank testing is performed at low rotational speeds (typically between 20 and 100 rpm). A load is applied by braking the driven side which ensures constant tooth surface contact. The angular positions of both pinion and gear are then recorded by measuring the time intervals between encoder lines. The transmission error curve results from the deviation in rotating angle between the signals from the two encoders taking the transmission ratio into account. The patterns in the transmission error curve originate from eccentricity (runout) in rotation of the pinion and gear and from the tooth meshing. This is observed in the form of a fairly regular once-per-tooth pattern superimposed on larger waves which are related to once-per-revolution type errors. The once-per-tooth (or faster) short wave components of the curve result from tooth meshing problems caused by surface structure effects and tooth geometry. The long wave portion is due to runout errors. Additionally, components due e.g. to support structure bolts may be present which bear no relationship to tooth geometry.

2.2 - Airborne Sound and Structural Noise Analysis

In order to obtain a more complete picture of the gearset's running behaviour additional signals may be acquired synchronous to the encoder data. Such signals often include structural noise on the bearings and airborne sound.

3 - Upgrade

In this section, the additional instrumentation and sensors required for single flank testing and airborne and structure-borne sound measurement and analysis will be outlined.

Section 3.1 contains details on the **rotec**-RAS system as well as a description of transducers and sensors used. The magnetic particle brake used for applying the loads on the output side is described in Section 3.2.

3.1 - Instrumentation

Rotation Analysis System rotec-RAS

Rotec GmbH, located in Munich Germany, specialises in the design and manufacture of portable, pc-based equipment for the measurement and analysis of noise and vibration. The Rotation Analysis System RAS (Figure 3) is designed for synchronised multichannel acquisition and analysis of both digital and analogue signals. Digital signals originate from rotational speed sensors whereby analogue signals are provided by accelerometers, microphones, strain gauges etc. A 100MHz quartz oscillator serves as time base for all RAS measurement channels to ensure that accurate, synchronised measurements across all channels are achieved. This eliminates any time or phase errors when performing cross-channel analysis.

Figure 3.1 RAS - Front Panel

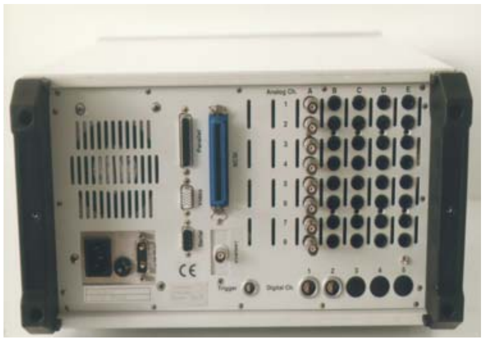

Figure 3.2 RAS - Rear Panel

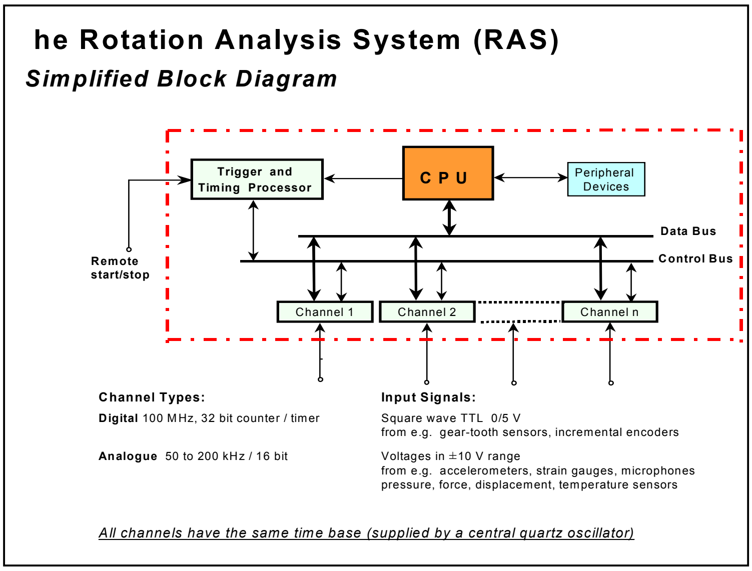

Figure 3.3 RAS Schematic

When performing single flank testing with the RAS each single graduation line on the encoders is evaluated and an exact reproduction of tooth meshing patterns results. Since order analysis of all data is possible, accurate correlation between, for example, noise levels and tooth meshing may be made. [1,2].

Incremental Encoders, Accelerometer and Microphone

Figure 4 shows pinion and gear wheels mounted on input and output spindles. The microphone is located slightly above the two wheels. An incremental rotary encoder is integrated into both the input and output spindles (screened from view). An accelerometer is mounted on the output spindle bearing (also not visible). The specifications are as follows:

- Incremental rotary encoders: line count 2048.
- Microphone: sensitivity 25 mV / Pa.
- Accelerometer: sensitivity 1000 mV / g, range 5g.

Figure 4 Microphone positioned above gearset mounted on input and output spindles.

3. 2 - Magnetic Particle Brake

The magnetic particle brake fitted to the end of the output shaft is shown in Figure 5. The brake is capable of generating braking moments up to 30Nm and ensures constant moments independent of rotational speed. The brake assembly unit is resistant to wear and requires minimal maintenance. The moments are directly proportional to the electric current supplied. This current is set with a rotary switch on the brake's control unit. Current values are recorded by the RAS system, converted to moments and protocolled for further analyses. An overview of the upgraded machine including the RAS system is shown in Figure 6.

Figure 5 Magnetic particle brake assembly.

Figure 6 Overview of the upgraded machine.

4 - Results

The **rotec**-RAS system was used for acquisition of the TTL pulse train signals from the rotary encoders and voltage signals provided by the accelerometer, microphone and brake control unit. Comprehensive RAS data acquisition and analysis software allows the user to easily configure the test and document the results. Gearset parameters, rotational speed, braking moments, amplitudes of tooth mesh orders, harmonics of tooth mesh, ghost harmonics, DIN characteristic values, etc. may be easily protocolled to produce, for example, a single line of information per gearset and a complete protocol file per shift.

The RAS system is fitted with an Ethernet interface which allows viewing of the test protocols from external PCs. This enables continuous monitoring of the quality of gearsets during production runs.

Single Flank Testing

The following notation is based on German DIN Standards (original German terms in *italics*).

F'_i total or cumulative transmission error *(Einflanken-Wälzabweichung)*

f'_l long wave component *(langwelliger Anteil)*

f'_k short wave component *(kurzwelliger Anteil)*

f'_{max} maximum value of tooth-to-tooth error *(Einflanken-Wälzsprung)*

In addition, f'_{mit} = average value of tooth-to-tooth error is calculated.

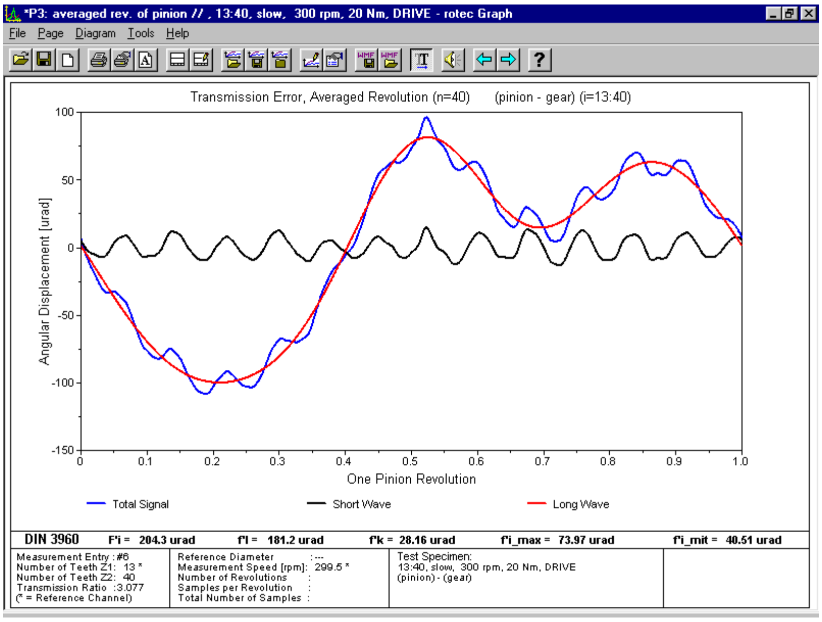

Figure 7 The transmission error curves show the deviation between the actual position of the driven wheel and the position it would occupy if the gearset were perfectly conjugate.

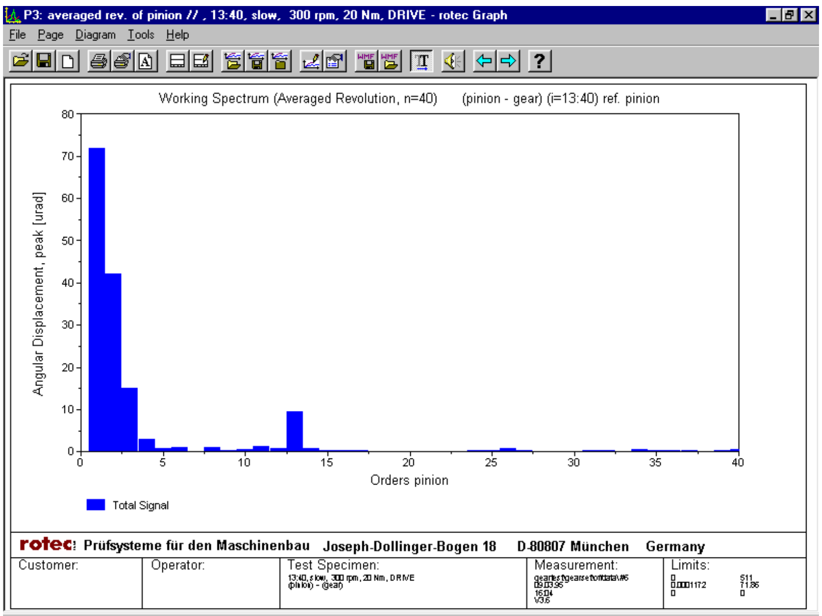

Figure 8 The spectrum of the total transmission error includes the tooth meshing order, its harmonics and side bands.

References

[1] RAS, Version 3.6 User's Manual", Rotec GmbH, Munich, 2000

[2] S. Adamson, "Measurement and Analysis of Rotational Vibration and other Test Data from Rotating Machinery", SAE Technical Paper No. 2000-01-1332