TORSIONAL OPERATIONAL DEFLECTION SHAPES (TODS) MEASUREMENTS

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ABSTRACT

This paper describes the concept and basic technique of measuring torsional operational deflection shapes using a laser-based torsional vibration meter, a dual-channel FFT analyzer and operational deflection shapes software running on a PC.

Torsional Operational Deflection Shapes (TODS) is defined similar to ODS (Operational Deflection Shapes), with the exception that TODS designates the operational deflection shapes of structures vibrating in a rotational, or angular, degree of freedom. Thus the TODS measurements can be applied to rotating shafts and the results of such a measurement are shown. In some cases it may be great benefit to apply order tracking and/or synchronous time domain averaging techniques in order to avoid smearing and reduce noise problems.

INTRODUCTION

Operational Deflection Shapes (ODS), designates the periodic motion pattern of a vibrating structure at a specific frequency and under a particular stationary, operating condition. An ODS is an observation, or visualization, of a particular dynamic behaviour. ODS of a vibrating structure can provide very useful information to aid in the understanding of the dynamic behaviour of a machine, a component or an entire structure, in particular when searching a solution to a dynamic problem [1].

Torsional Operational Deflection Shapes (TODS) are defined similar to ODS, with the exception that TODS designates the operational deflection shapes of structures vibrating in a rotational, or angular, degree of freedom. Determining the ODS, or TODS, of a structure requires the measurement and analysis of the response signals from the vibrating structure.

MEASURING ANGULAR OR ROTATIONAL VIBRATION

Measurement of angular vibration, particularly in the field, has heretofore posed several practical problems. Conventional angular vibration transducer systems have required the insertion of sensors such as strain gauge sensor modules, gear tooth wheels or optical encoders requiring the "breaking" of shafts unless located at a shaft end, or have been restricted to accessible portions of the shaft system. Signal conditioning and phase demodulation processing add to the problems by limiting the frequency range and dynamic range of the measurement. Furthermore, calibration is usually difficult to perform [2].

The Brüel & Kjær Torsional Vibration Meter Type 2523, provides a fast and easy means of measuring angular vibrations anywhere on a visible part of a rotating shaft, fulfilling one of the most important demands for measuring torsional operational deflection shapes, namely the ability to move the angular vibration transducer to a set of measurement positions.

The Torsional Vibration Meter Type 2523 is based on a patented dual laser beam principle where two laser beams are radiated from a laser transducer and pointed towards the shaft, rotating with at least 30 RPM (optionally down to 5 RPM).

The amount of measured Doppler shift in the two laser beams is proportional to the rotational speed, which is measured directly in RPM.

Any angular vibrations in the shaft, superimposed onto the steady rotational speed of the shaft, will be detected as well, causing the signal on the detector to be frequency modulated at the same frequency as the frequency of the measured angular vibration.

The Torsional Vibration Meter requires retro-reflective tape to be attached around the shaft [3].

MEASURING TORSIONAL OPERATIONAL DEFLECTION SHAPES

Expanding a normal, i.e. a one-plane, angular vibration measurement with a TODS measurement can be extremely useful in many applications.

The most important benefit of a TODS measurement is that it provides an animated picture of the torsional deformation at critical frequencies (typically a harmonic component close to a torsional natural frequency) under operating conditions.

A visualization of the torsional deformation shape provides a better understanding of the vibrational problem and consequently, this can help in creating the basis for a better solution to the problem.

APPLICATIONS OF TODS

Torsional vibrations in rotating shafts are well-known as sources of numerous vibration problems. Typical problems within the automotive industry and the marine engine industry include: Lack of power-train smoothness and quietness, gear rattle noise, reduced engine performance and reduced reliability [4, 5, 6].

EQUIPMENT FOR MEASURING A BASIC TORSIONAL OPERATIONAL DEFLECTION SHAPE

The Torsional Vibration Meter Type 2523 measures the angular vibrations in a single plane giving a calibrated output in millidegrees/second (angular velocity) or in millidegrees (angular displacement). Thus, when measuring the Torsional Operational Deflection Shape, subsequent measurements must be performed at different planes along the shaft where the phase of the torsional vibration between the different planes must be determined as well. A Brüel & Kjær Tacho Probe

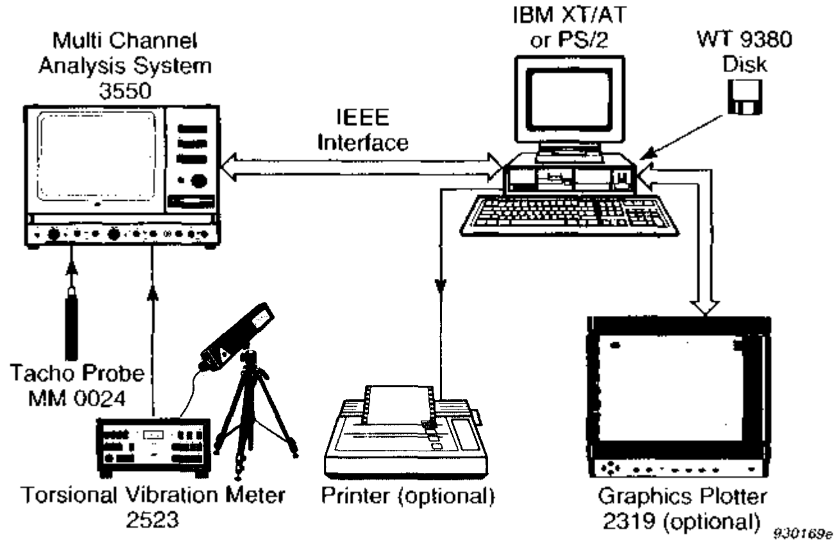

Fig.1 TODS set-up with instruments

MM 0024 is used as a reference transducer to obtain this phase information. Fig.1 shows the set-up.

The Torsional Operational Deflection Shape measurement is therefore performed by fixing and aiming the tacho probe at an arbitrary point on the shaft and moving the Torsional Vibration Meter Type 2523 along the shaft, measuring at different positions. At each point, the Torsional Vibration Meter Type 2523 will provide the torsional vibration amplitude (in millidegrees or degrees/second depending upon the mode of operation). Channel B of the Multichannel Analysis System Type 3550 is connected to the AC output of the Torsional Vibration Meter Type 2523 and Channel A is connected to the Tacho Probe MM 0024.

At the frequency of interest, i.e. the torsional natural frequency being excited, the Complex Spectrum of the Multichannel Analysis System Type 3550 will provide the vibration amplitude as well as phase information. However, no manual data interpretation is required: the Personal Computer, running the WT9380 Operational Deflection Shapes Software, is used for complete analyzer control, transfer of transmissibility data, data processing and deflection shape presentation (animation).

MEASUREMENT SETUP

A Torsional Operational Deflection Shapes measurement was performed on a thin steel shaft with two aluminium flywheels, rigidly mounted at the ends of the shaft. The shaft, symmetrically built and supported by six roller bearings, is made to rotate, at variable speed, by means of an electric motor. This mechanical system possesses a number of natural frequencies (in the translational as well as in the rotational degrees of freedom), of which the first torsional natural frequency is excited by two permanent magnets mounted in two of the bearing housings and two other magnets are positioned at equal distance, on one of the aluminium flywheels.

When the shaft was rotating, the speed of rotation was fine-tuned to coincide exactly with the first torsional natural frequency, thereby creating a (stationary) torsional resonance situation. The torsional operational deflection shape were as seen in Fig.2, i.e. the two ends of the

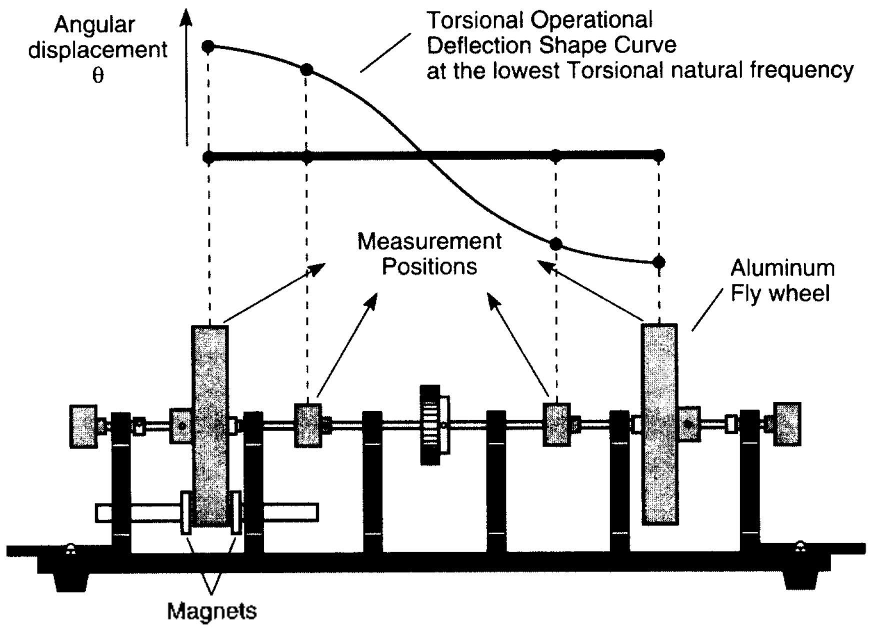

Fig.2 A thin steel shaft with two aluminium flywheels

shaft have the same torsional vibration amplitude, but a phase difference of approximately 180°. The nodal point is found to be in the middle of the shaft due to the symmetrical design. Four measurement positions were defined as indicated in Fig.2.

MEASUREMENT RESULTS

The result of the direct TODS measurement, i.e. the absolute angular vibration measured at the four measurement positions and the relative torsional vibration between the four measurement positions, are shown in Fig.3 as a print-out from the WT9380 ODS-software. The TODS frequency is identified to be 17.0 Hz within a "curvefit" bandwidth of 10 Hz and a resolution of 0.5 Hz. The data type is velocity, since the output of the Torsional Vibration Meter is proportional to the angular velocity.

The DOF (Degrees of Freedom) column specifies the four measurement positions. Due to the fact that cylindrical coordinates have been used the suffix 2 designates that the measurements are performed in a rotational degree of freedom

Both relative as well as absolute numbers are displayed. Therefore it is easy to identify that DOF 4/2 shows the highest level of angular vibration corresponding to RMS values of 2.76 degrees displacement corresponding to 295 degrees/second velocity and 31.500 degrees/s^2 acceleration.

The scale factor can be changed if peak values or peak to peak values are preferred, or if a recalibration is needed. The phase indicates that DOF's 1/2 and 2/2 are approximately in opposite phase of DOFs 3/2 and 4/2.

The relative torsional vibration (amplitude and phase) between the measurement positions forms the basis for the computer to create the TODS animation, which is shown in Fig.4.

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Operational Deflection Shape # 1

Set #: 1 — ODS Frequency: 17.00

Center Freq.: 17.00 — Bandwidth: 10.00

Scale Factor: 1.000 — Data Type: Velocity

DOF	Relative Amplitude	Relative Phase	Acceleration	Absolute Velocity	Displacement
1/ 2	0.979	165.	30.9 K	289.	2.71
2/ 2	0.470	168.	14.8 K	139.	1.30
3/ 2	0.417	18.	13.2 K	123.	1.15
4/ 2	1.000	0.	31.5 K	295.	2.76

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Fig.3 Listing of the TODS values

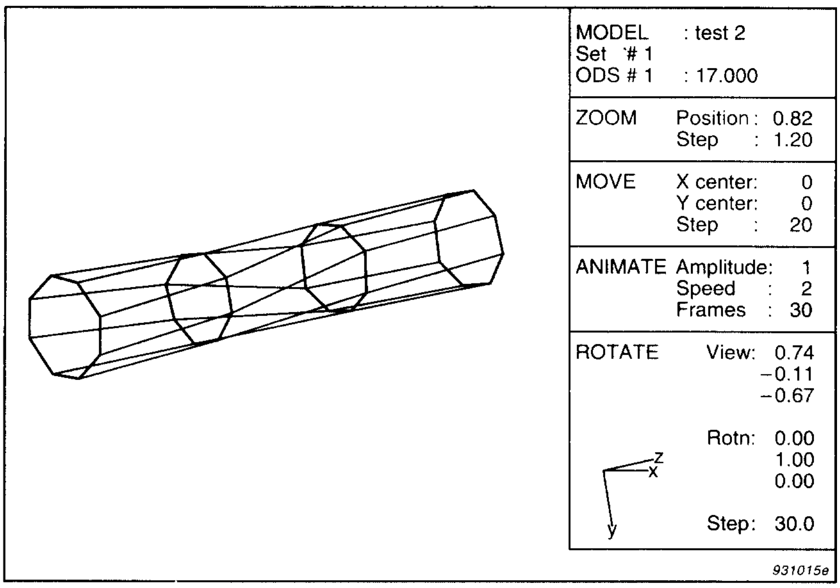

Fig.4 Animated TODS at 17 Hz

Using a simpler geometry, the animation can also be displayed as indicated in the upper part of Fig.2. For detailed information, see ref. [7].

CONCLUSION

Advancing the analysis possibilities of traditional one-plane angular vibration measurements, the Torsional Vibration Meter Type 2523 can be used to measure the Torsional Operational Deflection Shape (TODS) of rotating shafts, rotating at a critical frequency. The instrumentation is based on the Multichannel Analysis System Type 3550, controlled by a Personal Computer running the Torsional Operational Deflection Shapes Software WT 9380.

Measuring the TODS of a rotating shaft means that torsional vibration problems can be investigated by viewing the deflection shape and thereby guide the vibration engineer in making optimal design modifications to control vibration and less wear and fatigue.

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