

Application Note

Solving a Critical Propulsion Problem at Volvo Penta using Two Torsional Vibration Meters Type 2523

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Abstract

Any larger ship is a sophisticated and complex construction, and, concomitantly, building such ships involves many different aspects of engineering. Among the aspects of primary concern is the design of an efficient propulsion system.

In order to achieve a high degree of customer satisfaction, reliability, fuel efficiency and long overhaul intervals are of paramount importance for a high quality marine engine/propulsion system. For a naval ship, notably in a patrol or combat situation, the question of reliability is, for obvious reasons, of vital importance.

This Application Note describes and examines the use of two Torsional Vibration Meters Type 2523 in a critical, severely time-limited, trouble-shooting situation where the performance of a torsional vibration elastic coupling, fitted to the propulsion system of a new series of smaller navy vessels, had to be thoroughly investigated in order for the propulsion system to be cleared for operational service.



Preparing for a differential torsional vibration measurement at the Volvo Penta Marine Test Center, in Gothenburg, Sweden

Introduction

When a shaft transmits mechanical power through rotation, a torque acts on it. The crankshaft of a marine diesel engine is subjected to both a static, or constant, torque and to a dynamic variable torque. The static torque arises from friction and the applied load. The dynamic torque arises primarily from the pressure pulses due to the combustion process and secondarily from the unbalanced inertia loads in the slider crank mechanism used to achieve the reciprocating motion.

As a result of these gas and inertia forces produced by the marine diesel engine, harmonic torque components

are generated in the engine and in the propulsion system. These harmonic torque components will manifest themselves as torsional vibrations that can endanger mechanical components such as the crankshaft and the entire propulsion system, possibly causing fatigue failures. The phenomenon of critical engine speeds is closely related to this and occurs in marine diesel engines and propulsion systems whenever one of the harmonic torque components, exerted on the crankshaft system, coincides with a torsional natural frequency of the shaft system thereby creating a resonance.

A number of different counter measures are available to minimize the concomitant problems [1]. To prevent the built-up of large torsional vibration amplitudes and stresses at resonance, a so-called detuning device is often employed at the "free" end of a crankshaft. This device is typically used in applications involving complex, interconnected mechanical systems. For less complex and less severe applications, a simple elastic damper is often employed as it provides functional simplicity. The elastic coupling was an ideal choice for the directly driven propulsion system employed in the vessels to be de-

scribed later in this Application Note and was hence chosen as a means of reducing the levels of torsional vibration in the propulsion system (torsional transmissibility is typically reduced by 20 dB per frequency decade above resonance). Fig.1 shows a drawing of the torsional vibration elastic coupling that is employed in these vessels.

Torsional Vibration Meter Type 2523

Measuring torsional vibrations of rotating components is a notoriously difficult problem. Conventional torsional vibration transducers, such as torsionographs, shaft encoders, toothed wheels and magnetic transducers, have not only required excessive down-time of the machinery under investigation (due to a troublesome mounting and alignment procedure), but, equally important, they have “challenged” the skills of the vibration engineer due to the fact that most of these conventional torsional vibration transducer types are subjected to “noise” problems if the rotating target or structure to which the transducer is attached, vibrate as a solid body.

In a trouble-shooting situation the task of the vibration engineer is very often to establish the cause of excessive noise or vibration and subsequently propose a possible cure for the problem at hand. In such a situation the above-mentioned problems, when measuring torsional vibrations, are in most cases unacceptable to say the least, especially since most trouble-shooting tasks are carried out under a severe time pressure. Adding to this, the nature of trouble-shooting work often prevents the vibration engineer from knowing anything about the source of the excessive vibration.

All together, this has meant that a more efficient means of measuring torsional vibrations has been requested — especially for proper torsional vibration trouble-shooting work in-situ.

Based on a low-power dual laser beam principle, the patented Torsional Vibration Meter Type 2523 provides, without physical contact to the specimen, an accurate and durable means of measuring the torsional vibrations of a rotating object. Apart from attaching a piece of retro-reflective tape around the shaft (needed in

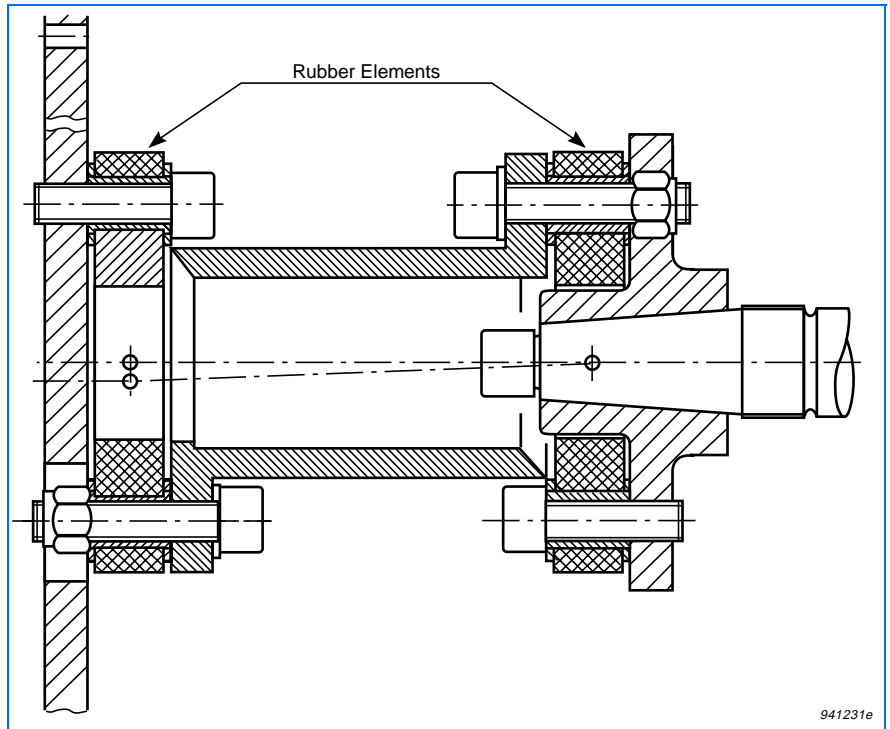


Fig.1 The elastic coupling used in the G-boat



Fig.2 Torsional Vibration Meter Type 2523

order to ensure sufficient light back-scattered into the instrument) the measurement object requires no preparations whatsoever. Due to innovative optical design, the instrument requires no on-site calibration or focusing. Fig. 2 shows the instrument. A thorough explanation on the work-

ing principle of the Torsional Vibration Meter Type 2523 is outside the scope of this Application Note.

See references [2—4] for more information on this subject.

Volvo Penta

Volvo was founded in 1927 by the two Swedish engineers Gustav Larsson and Assar Gabrielsson who had come up with new and intelligent ideas for an automobile. Established in Gothenburg in the south of Sweden, the company soon grew to be a successful manufacturer of private vehicles and trucks. With an accumulated high level of knowledge in the field

of combustion engines and transmissions, it was only natural to expand the activities of the Volvo company into designing and producing engines for marine vehicles. This part of the Volvo Group is known as Volvo Penta.

Specializing in marine engines and aquamatic stern drives for smaller and mid-range boats, Volvo Penta has become a world-leading company in

its field, bringing a number of innovative products to the market over the years. The headquarters of Volvo Penta, situated at Gothenburg in Sweden, employs at present more than 500 people.

The G-Boat and the Waterjet Propulsion System

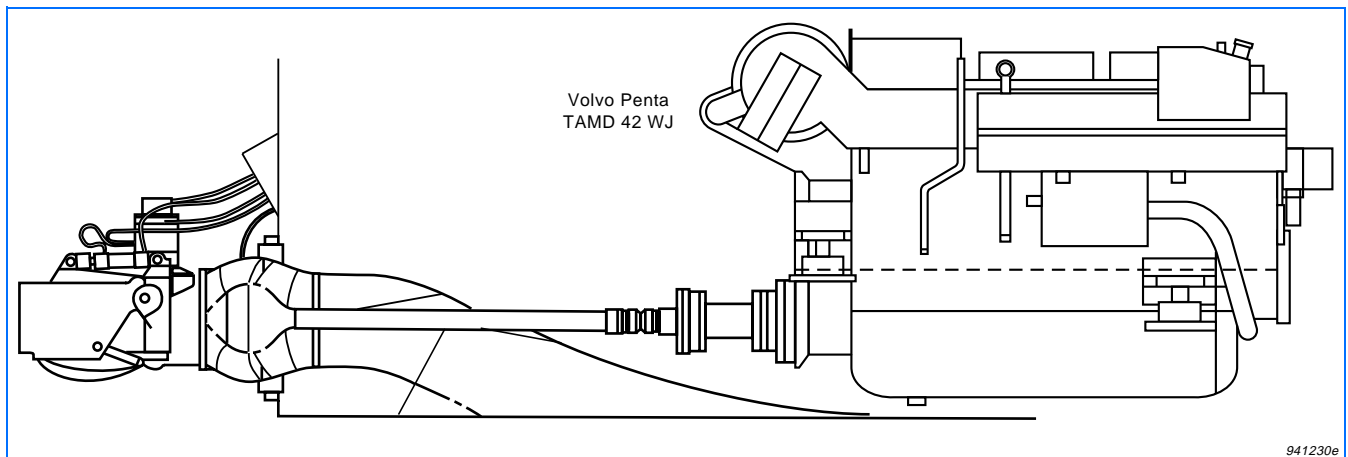


Fig.3 The Waterjet propulsion system with the TAMD 42WJ engine

For highly specialized sea transportation purposes, the elite unit of the Swedish Navy employs smaller vessels known as G-boats. To improve the performance, handling, ruggedness and manoeuvrability of this type of naval craft, an advanced waterjet propulsion system — instead of a traditional propulsion system with a propeller — was proposed when the Swedish Navy ordered a new series of these G-boats at a Finnish ship-

yard. Volvo Penta, being chosen as the sub-supplier for the engines, delivered a 6-cylinder/170 kW engine, known as the Type TAMD 42WJ, for this demanding application.

The layout of the engine and the propulsion system in the G-boat is shown in Fig.3. The waterjet propulsion system is directly driven by the in-line 6 cylinder, 170 kW, engine. All sea manoeuvring is undertaken by pivoting and tilting the waterjet out-

let tubes. In order to minimize vibrational problems, the propulsion system was finally designed with an elastomer rubber coupling for torsional vibration damping and four elastomer engine mounts functioning as translational vibration elastic couplings.

Introducing the Problem

Optimum Noise-and-Vibration-Harshness (NVH) characteristics of the power unit/propulsion system can obviously only be obtained when choosing a correct (matching) elastic coupling for the specific application. The Reich coupling Type 26998A3 were suggested by the shipyard (boat builder). Calculations performed by the calculation department at Volvo Penta showed that the couplings

could be approved. A number of these elastic couplings were ordered and built into the first series of the new G-boats.

Based on more than four hundred hours of extensive sea trials, some changes were proposed to the waterjet system (and soon implemented) to further improve the performance of the vessel. This, however, led to new dynamic characteristics of the en-

gine/propulsion system, thereby challenging the design team with two obvious questions: “Are new torsional vibration elastic couplings needed for the up-coming series of G-boats?” and even more importantly: “Are new torsional vibration elastic couplings needed for the series of G-boats all ready in operational service?”

Using In-situ Measurements to Solve the Problem

The Volvo Penta Calculation Department performed a new series of calculations in order to provide an answer to these vital questions. The result of the calculations raised doubt regarding the capability of the chosen coupling to absorb the vibration energy at a critical speed — heating up the coupling in the absorption process. However, the extensive sea trial had indicated that the chosen coupling was serving flawlessly without any deterioration of performance.

Volvo Penta explains: “In connection with the chosen torsional vibration elastic couplings for the first

series of the G-boat, two choices were basically feasible for the shipyard. They could — at high cost — replace the couplings with new heavy-duty couplings, or, they could as a second alternative make use of our offer to perform a full-scale verification test of the existing couplings. The latter could be performed by measuring, as a function of the engine RPM, the maximum angular deflection between the input shaft and the output shaft of the chosen elastic coupling”.

Employing traditional torsional vibration transducers, the full-scale, in-situ verification test would have been

extremely cumbersome at best, leaving the first alternative (although expensive) as a best choice. Nevertheless, the Torsional Vibration Meter Type 2523, employed in a dual configuration, i.e. with two instruments measuring differentially in real-time, enabled Volvo Penta to offer the cheaper, faster and much simpler second alternative to the shipyard.

Performing the Full-scale Measurement

The set-up used by Volvo Penta during the full-scale test on one of the G-boats is shown schematically in Fig.4. The TEAC RD200T digital tape recorder is used to record the AC output from the two Torsional Vibration Meters Type 2523 during the run-up measurement. The output signal from a tacho probe is recorded as well to allow for subsequent order analysis on a dual-channel FFT analyzer. Note that, as indicated on the figure, the phase of one of the Torsional Vibration Meters Type 2523 has to be inverted 180° in order to measure differential values of torsional vibration correctly [1]. Depending on the conditioning possibilities of the connected analyzing equipment, this phase inversion can either be achieved in this equipment, or it can be achieved by means of a simple 180° phase inversion feature, built-in to the Torsional Vibration Meter Type 2523 as a standard option.

During the measurement, the two Torsional Vibration Meters Type 2523 were mounted on their tripods, positioned directly on the engine room platform and loosely secured by means of tape. The two laser transducers were aimed at the coupling input shaft and output shaft respectively. Prior to the measurement, the shaft measurement positions were prepared with two pieces of retro-reflective tape. The actual set-up (though on a different type of boat) can be seen in Fig.5.

At this point, a number of important comments should be made.

Firstly, with the engine running, the engine room platform will obvi-

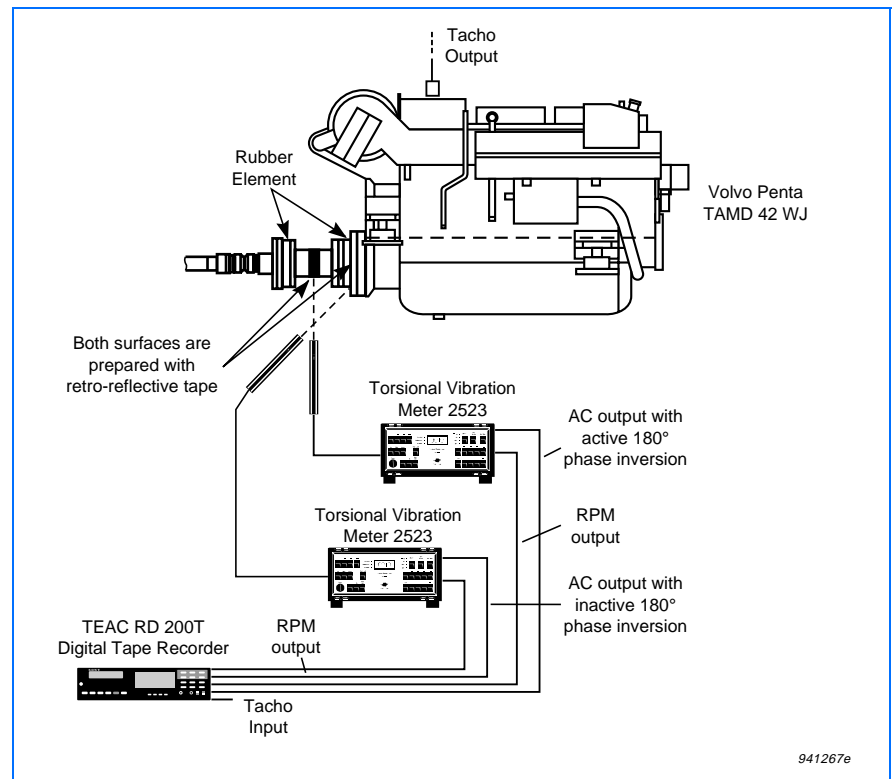


Fig 4 A schematical set-up used for the in-situ measurement of differential torsional vibrations across the elastic coupling

ously transmit vibrations (primarily translational vibrations) to the two Laser Transducers. However, translational vibrations (in any degree-of-freedom) of the measurement object and/or the Laser Transducer will have no influence on the torsional vibration measurement. This is due to the fact that the dual-laser beam principle of the Torsional Vibration Meter Type 2523 is inherently insensitive to translational vibrations [4].

Secondly, although no calibration of the Torsional Vibration Meter Type 2523 is required, a scaling factor has to be applied if the laser transducer is tilted or pivoted relative to the measurement object. Normal position (i.e. the position where no scaling factor is needed) is shown on Fig.6, whereas Fig.7 shows the situation where a scaling factor would be needed. The scaling factor can be calculated as the ratio of the actual speed

(for example, output from a tacho probe) to the apparent speed (rotational speed output from the Torsional Vibration Meter Type 2523) or it can be calculated as:

$$\frac{1}{\cos \theta} \cdot \frac{1}{\cos \phi} \quad (1)$$

when the pivoting angle θ and the tilting angle ϕ are known [2].

Thirdly, in a number of applications, the measurement object is not necessarily ring-shaped. Other geometries might well occur. However, the output of the Torsional Vibration Meter Type 2523 is totally independent of the cross-section geometry of the measurement object [2].

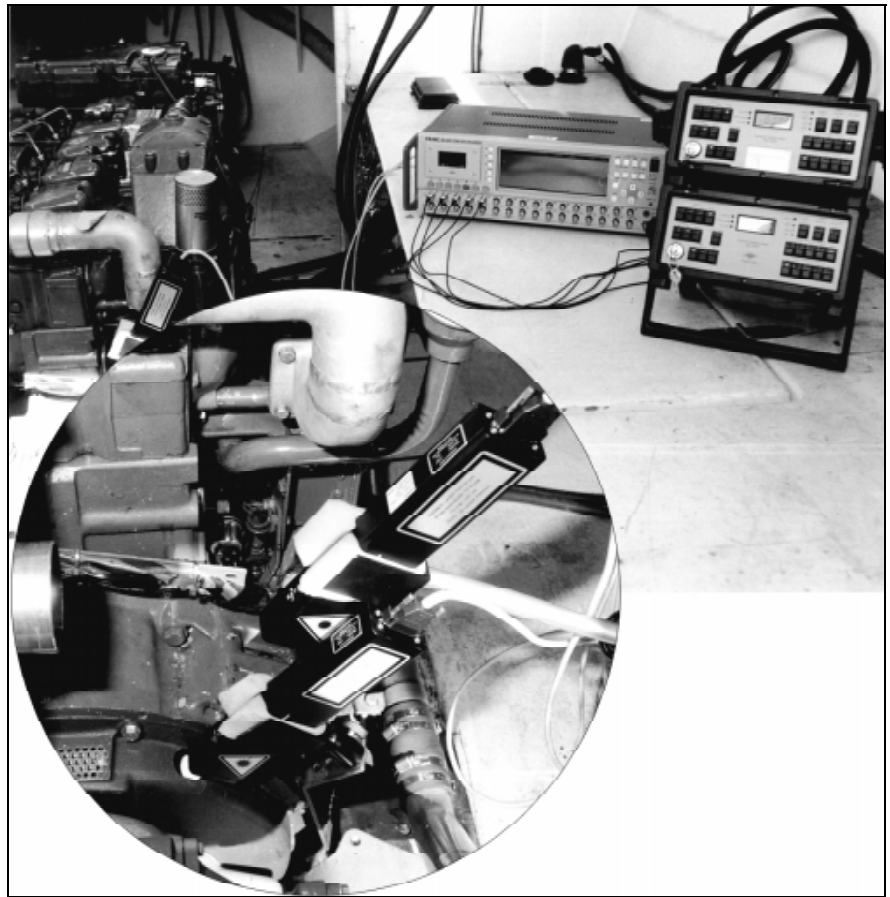


Fig.5 The actual set-up used. Along with the two Torsional Vibration Meters Type 2523, a TEAC RD 200T digital tape recorder is used to record the AC outputs of the Torsional Vibration Meters Type 2523 and a tacho signal. The latter was recorded to allow for subsequent order analysis on a dual-channel FFT analyzer

Result of the In-situ Differential Torsional Vibration Measurement

Having recorded the two AC output signals and the tacho signal on the digital tape recorder and analyzed them using order analysis, the measurement is finally transferred to a PC. With the aid of dedicated software, the PC then calculates the power generated in the elastic coupling as function of a chosen order. This calculation is based on the well-known formula

$$P_{\text{absorbed}} = M \cdot \omega \quad (2)$$

where: P_{absorbed} is the total absorbed power in the elastic coupling, M is the exerted torque on ditto and ω is the rotational speed. For order analysis, the exerted torque is calculated as:

$$M = 2 \cdot \sum_i \eta \cdot k \cdot \phi \quad (3)$$

where: i is the number of measured orders, η is the coupling efficiency, k is the rotational stiffness of ditto and ϕ is the differential torsional vibration amplitude as function of engine speed. The factor 2 is used since the

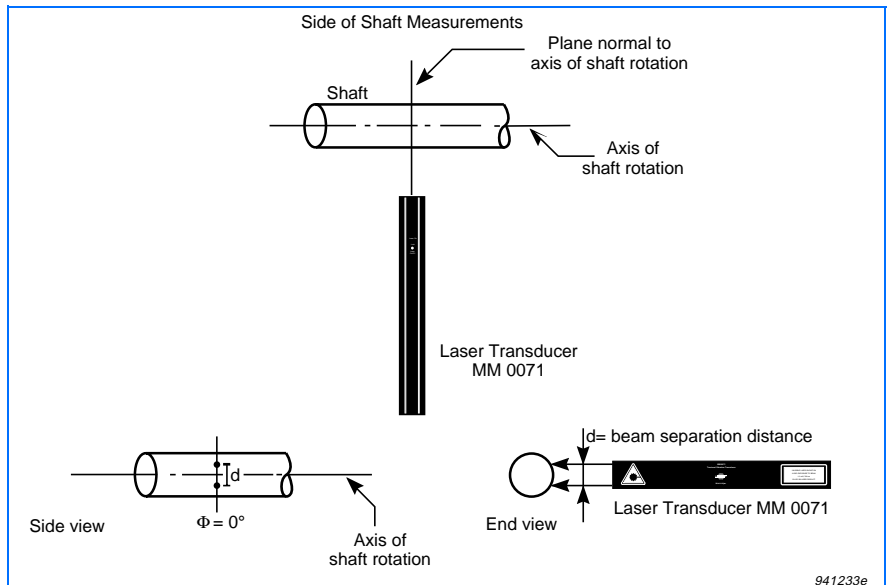


Fig.6 When the Laser Transducer MM0071 is neither tilted nor pivoted, a scaling factor is not required

differential measurement, as indicated on Fig.4, is carried out across the middle coupling section and the fly-wheel. Experience have shown that the two sections absorb very close to

half of the generated power and, accordingly, by multiplying with two, the total power absorption in the coupling is achieved.

$$P_{absorbed} = 2 \cdot \sum_i \eta \cdot k \cdot \phi \cdot \omega \quad (4)$$

where ω is now obtained by multiplying the rotational speed with the i 'th order.

The Torsional Vibration Meter Type 2523 as the Optimum Transducer for Torsional Vibration Measurements at Volvo Penta

One of the primary considerations for the design of Torsional Vibration Meter Type 2523 was to ensure that the dual laser beam optical principle would operate successfully even in troublesome industrial environments with a maintained high degree of confidence and accuracy. The outcome of these considerations is an instrument that, amongst other things, provides features as introduced in the previous sections: No focusing and no calibration needed, no sensitivity to translational vibrations of the laser transducer or of the measurement object, no sensitivity to the cross-sectional geometry of the measurement object.

For Volvo Penta these features are of special importance since many of their torsional vibration measurement tasks are carried out under less than ideal laboratory environments. The ruggedness of the Torsional Vibration Meter Type 2523 along with its ease of operation therefore played an important role when Volvo Penta decided on the optimum torsional vibration transducer for their needs.

Conclusion

By employing two Torsional Vibration Meters Type 2523 in a dual configuration, it has been shown how Volvo Penta were able to verify, in-situ, that the power absorption of torsional vibration elastic couplings, mounted onto the propulsion system of a series of Navy vessels, were within specifications. This verification avoided a costly and cumbersome coupling replacement. Despite difficult measurement conditions that included severe difficulty of access to the measurement positions at both sides of the coupling, the measurement was successfully performed, leaving no doubt that the chosen elastic couplings would operate flawlessly. Furthermore, practical aspects of employing two Torsional Vibration Meters Type 2523 in a dual configuration have been discussed.

The measurement indicated that the orders of interest were the 3rd, to the 6th. Fig.8 shows the total generated power in the elastic coupling at these orders. The maximum allowable value for the generated power is

9 W, whereas the measured value is approximately 4.5 W at 2700 RPM. Volvo Penta was therefore able to approve the originally chosen torsional vibration elastic coupling for the first series of the G-boat.

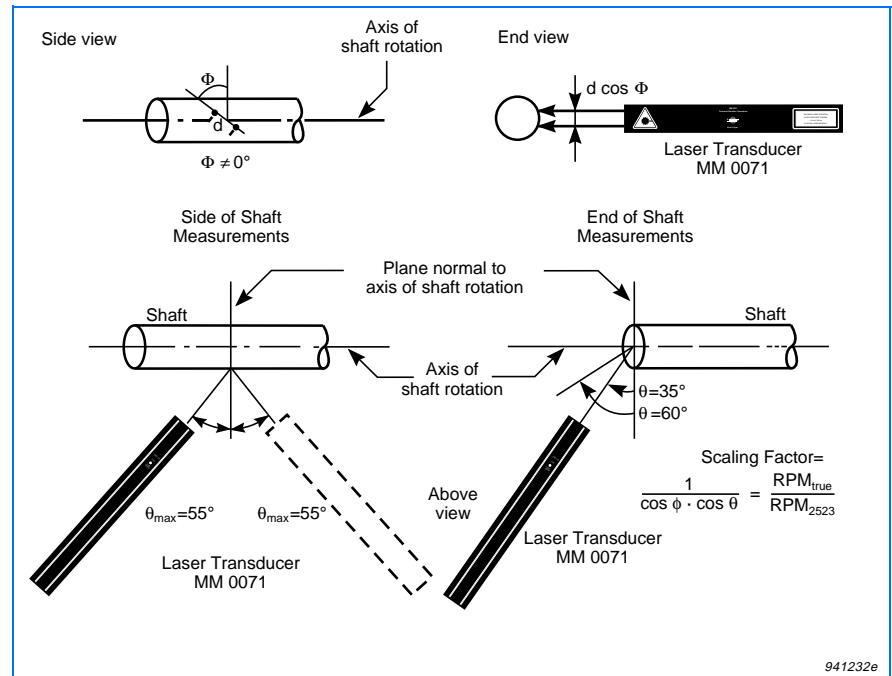


Fig 7 Applying a scaling factor to the calibrated output of the Torsional Vibration Meter Type 2523

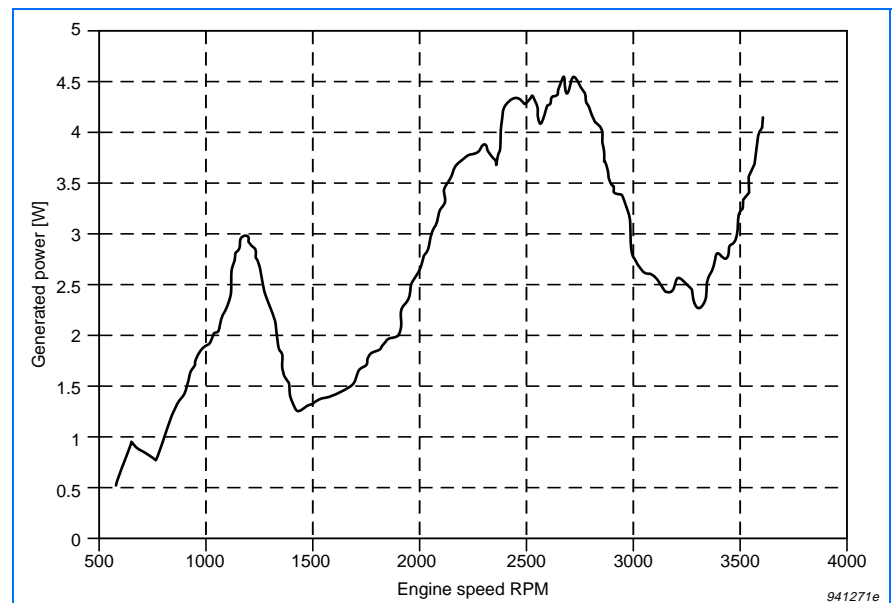


Fig 8 The power absorption in the elastic coupling as function of engine RPM. The limit for approval was 9 W

References

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