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Non-contact, miniaturized laser vibrometer for OEM integration

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Abstract
We present a novel laser vibrometer that remains cost effective and scalable for OEM integration, without having to compromise on measurement accuracy. Our design uses telecom technology and its miniature components instead of the historical Helium-Neon solid state laser technology and free beam optics. This crucial step enables miniaturization, mass production and cost reduction of laser vibrometers. Thus, these ultra-precise devices can now be embedded in complex assembly in a set and forget manner. The sensor's electronics performs a live Fast Fourier Transform (FFT) of the signal to allow on the fly monitoring of assembly's vibrations.

Keywords: Vibrometer, interferometry, non-contact sensing

1. Context

Precision engineering faces a growing need to investigate mechanical vibration frequencies and amplitudes in order to control them. For example, vibrations of a milling machine can produce erratic motions of the workpiece with regards to the cutter and hence, may lead to contouring errors or bad surface finish. The misshaped components could jeopardize the whole system's assembly or safe operation and would fail quality control criterions [1].

Laser vibrometers offer ultimate resolution and accuracy [2-4]. Yet measuring vibrations in a non-invasive way remains a challenge: with the miniaturization trends ongoing in manufacturing technologies, vibrometers must work in confined spaces difficult to access and of limited sizes. Moreover, they must prove cost effective and fit OEM (Original Equipment Manufacturer) integration, without having to compromise on measurement accuracy. So far modular and precise commercial devices fail to meet such needs and are too expensive for the industry market.

In the following we report a typical application for laser vibrometry and how our innovative solution was a crucial step towards miniaturization, mass production and cost reduction of laser vibrometers.

2. Case study

Few months ago, one of our partners designed a system, which embedded a rotating motor. While performing simulations, the design team found out that, in order to comply with the overall system error budget, the maximum vibration amplitude of the motor housing should fall behind 100 nm. They then needed to characterize the part vibrations, but lacked of a fast and accurate method to do it. We provided a solution.

First we emphasized that even minimal mass variations may induce dramatic shifts in vibration frequency / amplitude signature. We then discarded any contact sensors such as CMM probe calibration spheres or optical encoders as viable solutions. Likewise we excluded the use of capacitive sensors since our partner's setup design imposed a cylindrical geometry for the motor housing. The only technology left involved a non-contact, high accuracy interferometer.

Since we needed to demonstrate in-situ frequency analysis, we eliminated usual commercial testing / calibration products, which combine optics and electronics in their sensor probes. Indeed, they lack the required compactness. The remaining standard laser vibrometers link remote electronics to sensor probes by single optical fibres. Yet, the existing commercial solutions forsake system integration as OEM: most of them use large and expensive Helium-Neon laser (HeNe) as light source.

We designed a device using standard telecom components, thus offering scalability and fitting in a tight packaging (electronics footprint of 50 mm × 50 mm × 165 mm for a weight of 750 g). Besides its power supply requires only 5 W electrical power supplied in 12 V continuous voltages. Finally, it offers the standard industrial interfaces needed for convenient integration (etherCAT, CANopen, Profibus).

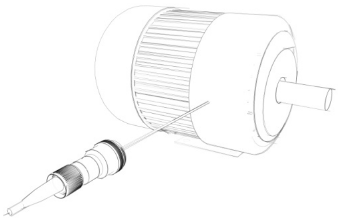

Figure 1. Schematic setup for measuring a vibrating object. When actuated, the motor generates vibrations, which are monitored by the laser interferometer.

We then performed a fast test measurement: we monitored and recorded the displacement of the motor housing as well as its live vibrations. Indeed, the sensor's remote electronics performs on the fly Fast Fourier Transform (FFT) of the signal. Figure 2 displays the setup vibrations versus frequency in the 5 Hz to 50 kHz range for motor spindle rotating at 500, 1000, or 2000 rotations per minutes (rpm).

The frequency analysis emphasizes that the present motor design couples vibrations at the fundamental frequency to its second and fourth harmonics. Though, this behaviour complies with design requirements for both lowest frequencies, it jeopardizes the system safe operation at 2000 rpm. Indeed, we evidenced that at such speeds the motor generates vibrations at 270 Hz. These amplify a system resonance at 345 Hz, which in turn drastically increase the overall vibration amplitude to a value exceeding the 150 nm limit. This crucial information triggered a design modification of the holder, which minimizes the system response to vibrations, and prevents potential failures.

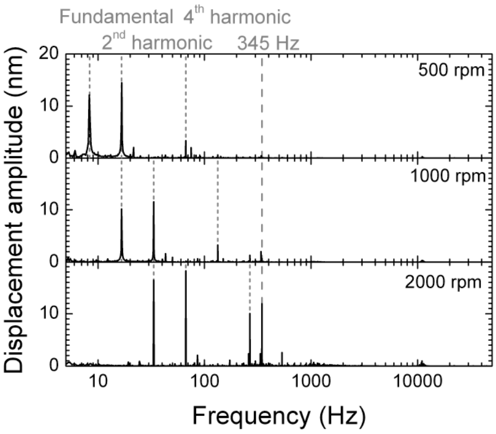

Figure 2. FFT of the displacement signal monitored in a 100 kHz bandwidth. The spindle motor ran at top: 500 rpm, middle: 1000 rpm, and bottom 2000 rpm. We evidenced vibrations at fundamental rotation frequencies as well as replicas at the 2nd and 4th harmonics (gray dot line). At 2000 rpm, the 345 Hz (gray dash line) system resonance is highly amplified.

3. Working principle

The IDS3010 is a laser vibrometer based on our patented technology [5] that offers ultimate resolution over meter range motion tracking (figure 3). A laser diode embedded in the IDS3010 electronics emits infrared light. This light is routed to a sensor head through an optical fibre circuit and output in free beam toward the object of interest. The object reflects part of the light back into the optical fibre towards a detector. This arrangement automatically creates a so-called “Fabry-Perot cavity”. Thus, the light intensity impacting the detector varies according to the object displacement. The IDS3010 electronics processes the detected signal, performs a FFT of the measured displacement, and outputs it in real time. This procedure extracts the amplitudes of the object vibrations versus their frequencies: it performs a frequency analysis.

The IDS3010 operate up to three sensor probes either directly integrated or remotely connected through standard optical cables to the electronic unit. In the remote electronics version, our innovative probe design ensures robust and easy installation, and removes the usual trailing cables’ vibration coupling of sensor probe to environment. Moreover it grants extreme compactness (the sensor head diameter can scale down to 1.2 mm diameter, see figure 3) and high mounting tolerance –so that even non-specialist can plug and start tracking their object displacement and vibrations within a few minutes. All in all, our design matches any modular and portable requirements.

The electronics locks the laser wavelength on a gas molecular absorption and allow extremely stable system operation –even at low frequency– as shown in figure 4. Therefore, our device competes with the traditional HeNe solid state lasers in terms of stability; yet the use of telecom wavelengths fits OEM requirements of scalability and allows savings for high volume production. This way production costs can fall down by a factor five to ten when compared to standard laser vibrometers.

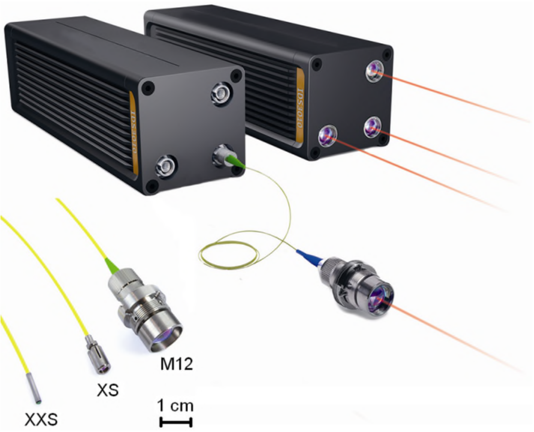

Figure 3. IDS3010: a compact laser vibrometer that tracks displacements with picometer resolution over meter range, and performs on the fly frequency analysis. Bottom left: different compact sensor probes, the smallest one reaching 1.2 mm in diameter.

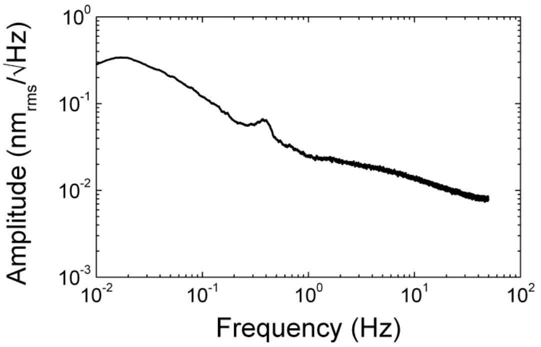

Figure 4. Noise spectral density of the laser vibrometer that lies below 300 pm/√Hz at room temperature (acquisition bandwidth: 100 Hz, data high path filtered at 10 mHz frequency).

5. Conclusion and outlook

We presented a novel laser vibrometer, which measures over the wide DC to 10 MHz range with sub-nanometric resolution and extremely low noise floor. Our sensor portability and ease of use initiates in situ fast monitoring of vibrations even by non-experts in laser interferometry.

We successfully used the innovative device to diagnose motor vibrations in real time or detect ultrasonic resonances of an actuator. The IDS3010 frequency analysis tool empowers on the fly diagnosis of machines in a production line without disrupting the manufacturing process. Production teams can then trace back unbalanced, misaligned, damaged, or loose components and trigger service or maintenance on time. This not only improves part quality, but also minimizes machine downtime. Our compact sensor design and high integration qualifies for the “Industry 4.0” challenges. We perceive it as a game changer in the single point vibrometry market.

References

[1] Stone B. Chatter and machine tools. Switzerland: Springer International Publishing; 2014.

[2] SP-S series laser interferometric vibrometer, SIOS GmbH. Ilmenau, Germany.

[3] OFV-55x Fiber-Optic Sensor Head, Polytec GmbH, Waldbronn, Germany.

[4] FPS3010 Interferometric Sensor, attocube systems GmbH, Munich, Germany.

[5] Karrai K, inventor; attocube systems AG, assignee. Device for position detection. United States Patent 20100259760. 2013 Oct 29.