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USING COMMONLY AVAILABLE NETWORK EQUIPMENT FOR LASER DOPPLER VIBROMETER EXCITATION AND CALIBRATION

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Abstract:
We have demonstrated that commonly available small form-factor pluggable (SFP) modules can be used for LDV excitation and calibration. While the expected intensity modulation at the photodiode inside the LDV interferometer is sinusoidal, the SFP module output is designed for and provides a rectangular modulation shape. The conducted experiments produced comparable results.

Keywords: Laser Doppler vibrometer calibration; SFP

1. INTRODUCTION

In [1] we presented a new method for laser Doppler vibrometer (LDV) calibration using an external amplitude-modulated laser source as an excitation source. For the HeNe laser-based LDV, a red laser diode roughly matching the HeNe wavelength was used, applying a driver capable of AM modulation up to 100 MHz.

Basic setup for LDV calibration

The photodiode, being the central sensing part of the LDV, cannot distinguish the cause of an intensity variation. Whether an intensity variation is the result of optical interference or is simply caused by a modulated external light source makes no difference. If an appropriate light source with a suitable modulation following (1) is targeted at its sensing element, the LDV response will be identical to the same interference caused by actual motion.

$$i(t) = i_0 \cdot \sin(2\,\pi\, f_{\mathrm{AOM}}\, t + 4\,\pi\, x(t)/\lambda + \varphi_{\mathrm{d}}) + i_{\mathrm{c}}. \quad (1)$$

$i(t)$ describes the current in the laser diode or photodiode, i_0 the modulation amplitude, i_c a constant current, f_{AOM} the carrier frequency of the LDV, $x(t)$ the displacement of the target (usually the device under test (DUT)), λ the wavelength of the LDV laser, and φ_d the phase offset.

Figure 1 shows a schematic LDV calibration setup. The laser diode (LD) is amplitude-modulated by a signal generator, which is preferably synchronized with the carrier of the LDV. A beam splitter (BS) feeds both the LDV and an external photodiode (PD) with known group delay as reference [2]. The use of an external reference PD omits the need to characterize the LD, including the LD driver and generator characteristics (mainly time delays and modulation depth). The analogue-to-digital converters (ADCs) synchronously capture the signals of the reference PD and the output signal(s) of the LDV (=DUT). The signal of the PD is sampled and numerically demodulated with the successive arctan2 method. For the optical simulation of sinusoidal/harmonic vibration, sine approximation methods are used to obtain the transfer function of the LDV [3], [4].

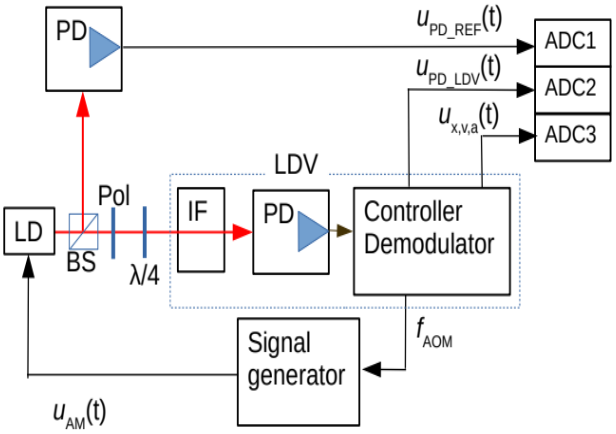

Figure 1: Basic LDV calibration setup with external laser excitation.

2. USING SMALL FORM-FACTOR PLUGGABLE (SFP) MODULES AS EXCITATION SOURCE

A growing class of LDVs now uses infrared laser sources, with most having a wavelength of 1550 nm and an output power of up to 10 mW. In addition, the heterodyne frequency and the bandwidth in some cases increases to 80 MHz and higher, resulting in bandwidths of up to 160 MHz and beyond. Such requirements demanded an upgrade of the laser diode setup [1]. While investigating the options for laser diode sources and drivers, we decided that it would be worthwhile to try out SFP modules developed for fibre optical networks.

SFP features at a glance:

1. Laser wavelengths of 850 nm, 1310 nm, and 1550 nm available
2. Power range approximately matches the LDV
3. Built-in laser driver with a bandwidth far beyond what is needed (>1 GHz)
4. Photodetector of same bandwidth included
5. Easily adaptable LVDS [5] connection for input and output
6. Depending on wavelength and power, very reasonable prices due to the mass market for IT infrastructure

The SFP breakout board shown in Figure 2 was built mainly to hold the SFP module, provide a 3.3 V power supply, provide a breakout for the LVDS input and output, and to toggle the enable pin of the SFP module. An additional µC-board reads the EEPROM of the SFP module to provide information about the laser wavelength of the actual SFP module.

The LVDS input of the SFP module has an input impedance of 100 Ω and is decoupled with two capacitors (this is the case for all SFP modules the authors have investigated). Hence, an additional 100 Ω SMD resistor connected in parallel is sufficient to match the 50 Ω impedance of the signal generator.

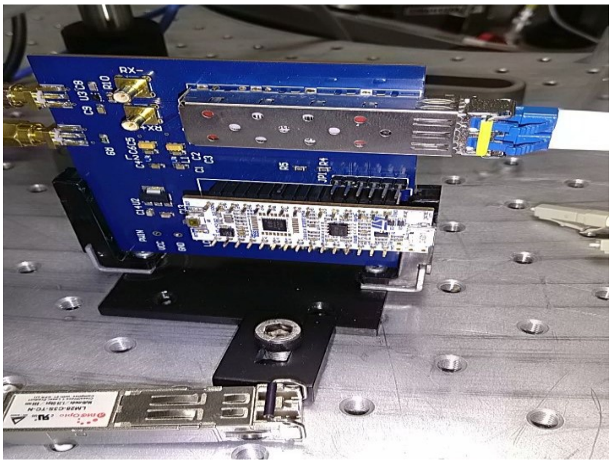

Figure 2: SFP breakout board.

Optical setup

In the first setup, a laser diode emitting mainly linearly polarized light at a wavelength of about 635 nm was used to excite a HeNe-based LDV. The optical power fed to the LDV was adjusted by a linear polarization filter followed by a $\lambda/4$ plate to match the circular polarization that the LDV expects in normal operation. The wavelength of the external exciting laser was selected such as to not exactly match the LDV internal laser wavelength. This was done to avoid (beating) interference if the internal laser cannot be completely turned off by a shutter.

The optical connectors of the SFP modules were of the LC UPC type, and a 1 m mono mode fibre with an FC UPC end was used to couple into air.

Three types of SFP modules were tested, one with 850 nm wavelength and about 0.3 mW power, another with 1310 nm and ~0.6 mW, and one with 1550 nm and ~9 mW.

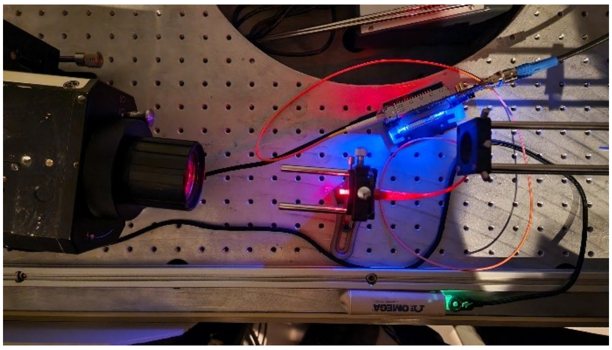

Figure 3: First setup, LDV directly focussed on the fibre connector ferrule.

The 850 nm type was successfully tested with a HeNe LDV (Polytec OFV 353 LDV head and an OFV-5000 Controller). The internal optics and the photodiode still work at this wavelength. This test was performed without reference PD and additional polarization filters. By choosing the minimal focus length of the LDV, the HeNe beam of the LDV was aligned to obtain a maximum coupling into the fibre, see Figure 3. Then the internal laser was deactivated and the other fibre end connected to the SFP module. A polarization optimum was found by twisting the fibre slightly. The emitting power of the SFP module was less than 0.3 mW, and only a low to moderate signal strength indicated at the LDV could be achieved with this setup. The insertion of a beam splitter for the reference photodiode again lowered the signal's strength and increased the noise level. A test with a 1550 nm IR LDV (VFX-I-120 head with VFX-F-110 Controller) resulted in no signal due to the optical filters inside the LDV.

The 1310 nm and the 1550 nm SFP module were tested successfully with the IR LDV. The reference PD used in [1] had to be replaced by a type appropriate for the longer wavelength (Femto Model HCA-S-400M-IN-FST). The determination of this PD's group delay is still an open task.

For this setup, an additional collimator lens was mounted after the fibre ferrule to improve the signal strength and obtain more space for the polarization lenses and the beam splitter.

3. TEST OF THE INFLUENCE OF MODULATION SHAPE

The amplitude modulation of the SFP module is of rectangular shape, while the expected intensity modulation at the photodiode inside the LDV interferometer is more of a sinusoidal shape due to the interferometric origin. Depending on the signal processing in the LDV, this may have an influence on the resulting LDV output.

Tests were performed with a 40 MHz carrier frequency and a simulated 5 kHz, 10 kHz and 20 kHz sine excitation with a velocity amplitude of 1 m/s. This resulted in a modulation depth of 3.159 MHz for the selected HeNe LDV.

One 850 nm module was modified to achieve a sinusoidal amplitude modulation while another was left unchanged. It was found that the transfer functions measured with both modules are equal within the standard deviation of both measurements in amplitude and phase. While the measurement uncertainty budget still needs to be determined, this result is a strong indicator that the shape of the amplitude modulation exerts only minor influence with this type of LDV.

4. USE OF THE SFP PHOTODIODE AS REFERENCE DIODE

Using the 1550 nm module (and its higher output power), the internal PD of the SFP was tested as a potential reference diode. The reference PD was replaced by another collimator to feed the fibre optic for the SFP input. The SFP PD has a built-in logarithmic amplifier and the output LVDS driver provides a rectangular signal of 100 Ω impedance. By adding an additional resistor to match the 50 Ω input impedance for the ADC and an antialiasing LP filter at 120 MHz, we were able to demodulate the signal. It was found that the lower frequency range is limited to frequencies greater than about 1 MHz to 2 MHz due to the internal signal conditioning. At lower frequencies, the logarithmic amplifier created erratic pulses in the module tested. Unless the full velocity range of the LDV needs to be tested, this behaviour is a minor limitation.

At least one analogue PD with DC capability within the applied wavelength is strongly recommended for the alignment.

5. SUMMARY

We have demonstrated that commonly available SFP modules are well suited for the stimulation and calibration of LDVs. While the expected intensity modulation at the photodiode inside the LDV interferometer is more of a sinusoidal shape and the SFP module output is designed for and provides a rectangular shape, the tested LDVs all showed comparable results.

The SFP's internal AC-coupled photodiode has a lower frequency limit in the lower MHz range and its delay time still needs to be determined for phase calibration purposes.

6. ACKNOWLEDGMENTS

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