Non-contact Acousto Optic Scanning Laser Doppler Vibrometer

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Brief introduction

Laser vibration-measuring system has the advantage of being non-contact in measurement of vibration. Some application requires not only point vibration measurement but also surface vibration at several critical points by deflecting the beam at different angles by what is called the scanning technique. Current scanning technique which employs deflection mirror, can not achieve very high measurement accuracy and positioning accuracy because of the unavoidable vibration of the mechanically driven mirror. In this paper we design a novel scanning vibrometer using Acouso-optical deflector. It overcomes the limitation of conventional scanning vibrometer.

Scanning technique

In order to get parallel scanning beam, the AO Deflector is positioned such that its optical axis is at the focal length of the collimating lens CL1 and CL2. Moreover the collimated beam incident on the AO deflector at the Bragg's angle of the acoustic crystal.

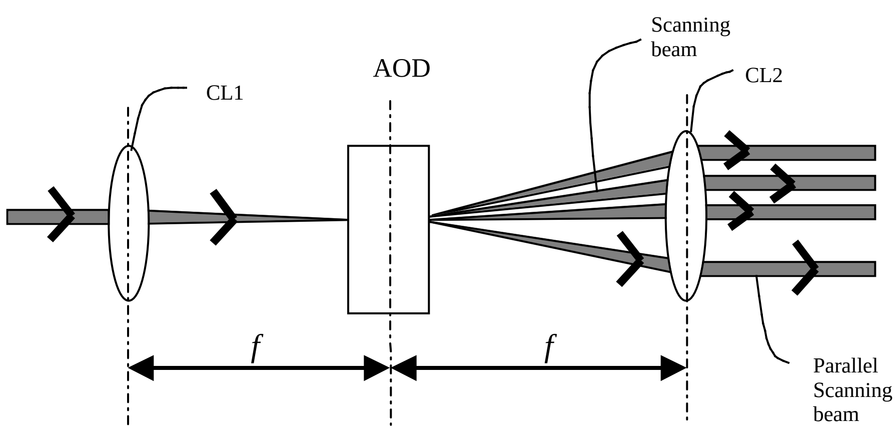

Fig.1 Optical system to generate parallel scan beams

Optical system design for a scanning heterodyne vibrometer

Referring to Fig.2, linearly polarised light from the laser source is modulated by an Acousto Optic Modulator (AOM). The Zero order beam from the AOM passes through a polarising beam splitter PBS1 where as the first order beam having a frequency shift with reference to the zero order beam(equal to the frequency of the acoustic wave in the AOM) is deflected by PBS1. The zero order beam acting as a measuring beam. It passes through a scanning system described as above.The parallel-scanning beam passes through the polarizing beam splitter PBS2 and the quarter wave plate WP1 to strike the target surface, whose dynamic characteristics are to be measured. The scanning beam thus reflected from the target surface, carrying the dynamic information is deflected by the PBS2 due to shift in the polarisation state by the WP1.

Similarly the 1st order beam from the AOM, which acts as the reference beam, is deflected by the PBS1 on to the deflecting mirror DM2. The Deflected beam has the optical path along the Collimating lens CL3, Acousto Optic Deflector AOD2 and collimating lens CL4 of the same configuration and purpose as the CL1, AOD1 and CL2 in the measuring beam path. The reference beam then strikes the reference surface via a quarter wave plate WP3. The polarising beam splitter PBS3 deflects the reflected beam where it is aligned with the measuring beam. The beam is focused by using an collimating lens CL5 and is made to interfere by the polariser P1. Also the 0th order beam from the AOD1 is made to interfere with the 0th order beam from the AOD2 by the polarising beam splitter PBS4 and the polariser P2. The photo detector 1 and photo detector 2 captures the interference signals.

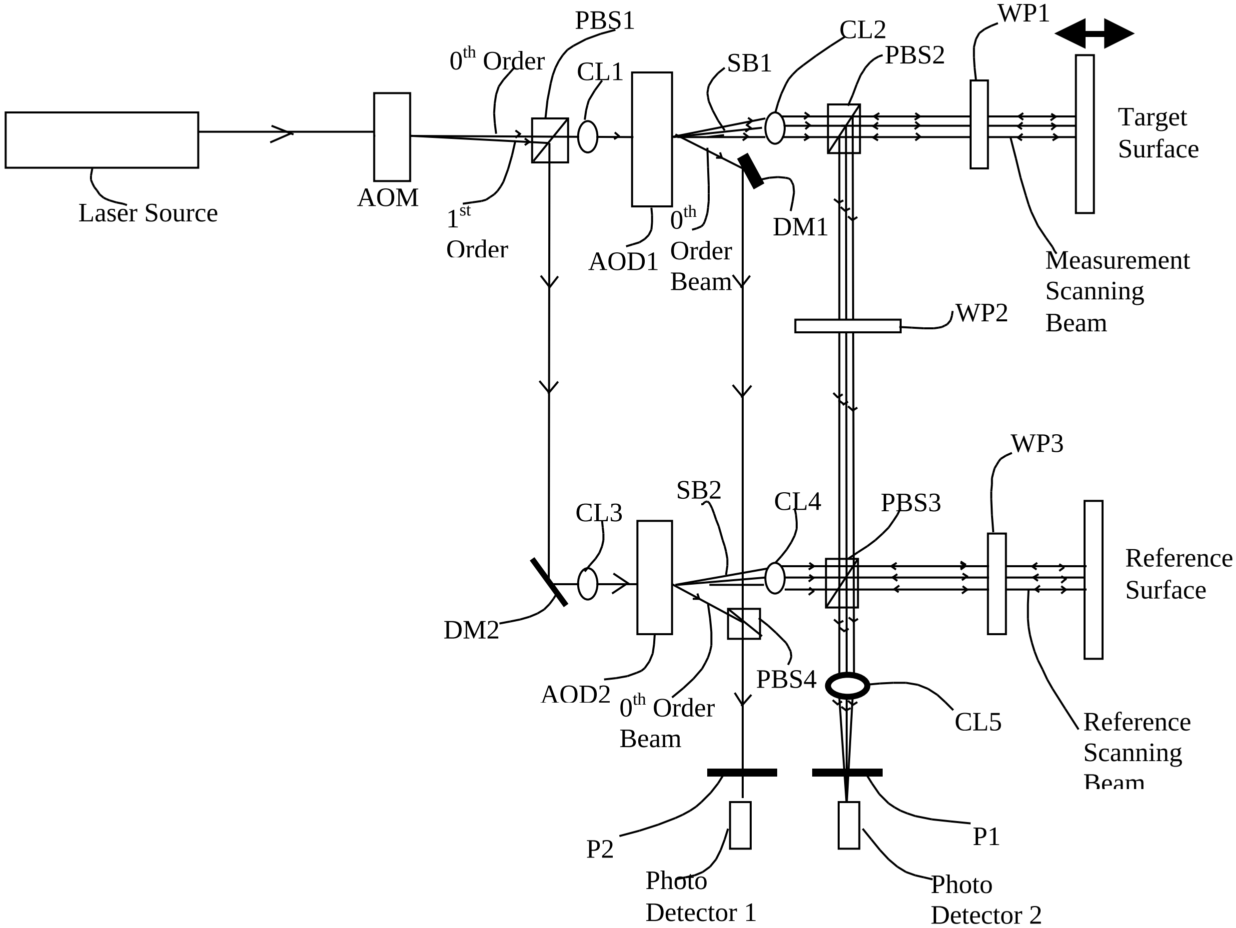

Fig.2 Optical Layout of the Scanning Heterodyne Vibrometer system

A common signal generator, whose signal is amplified by a common or independent power amplifier, drives the two Acousto Optic Deflector AOD1 and AOD2. The purpose of driving the two Acousto Optic Deflectors by a common drive is to obtain very precisely the same deflection angle for each of the input frequency. This is an essential factor for interfering the measuring and reference beam at each of the scan points automatically provided the beam was interfered at one of the scan points.

Interference mechanism of the measuring and the reference scanning beam:

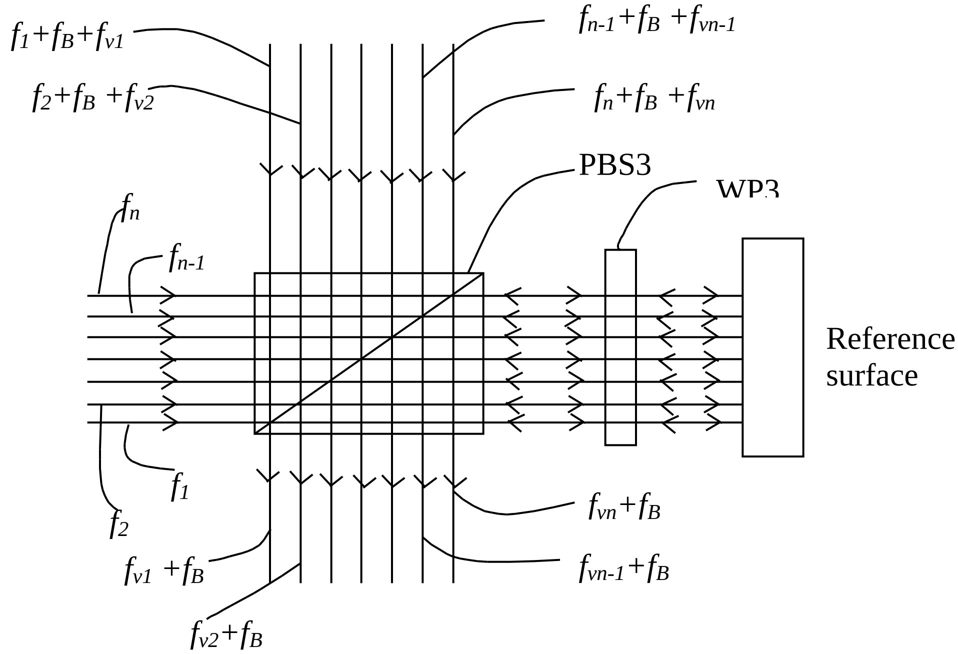

Fig. 3 Interference mechanism of the reference and measuring scanning beam

The Fig.(3) shows the interference phenomenon involved in this technique. The scanning first order laser beam from the Acousto Optic Deflector AOD1 has the minimum frequency shift of f_1 induced and the next higher level of frequency shift induced is f_2. Similarly the highest frequency shift induced is f_n and the highest but one frequency shift is f_{n-1}. All these frequency shifts are with reference to the frequency of the zero order beams. Same is the case with the Acousto Optic Deflector AOD2 since they are made of the same specification and driven by a common driving mechanism.

So the optical design is designed such that the measuring scanning beam from the AOD1 of frequency $f_1+f_B+f_{v1}$, $f_2+f_B+f_{v2}$,........$f_{n-1}+f_B+f_{vn-1}$, $f_n+f_B+f_{vn}$ interferes with the reference scanning beam from the AOD2 of frequency f_1, f_2, ……f_{n-1}, f_n. Where f_B is the frequency shift induced due to the Acousto Optic Modulator. Hence the resultant frequency of the interference beam is given by $f_{v1}+f_B$, $f_{v2}+f_B$, ….. $f_{vn-1}+f_B$, $f_{vn}+f_B$, where f_{v1}, f_{v2}, ……f_{vn-1}, f_{vn} are the frequency shift induced due to the vibration of the measuring surface at each of the corresponding scanning point. The photo detector 2 captures these interference signals. Also the zero order beam from the AOD 1 which has a frequency of f_o+f_B (where f_o is the frequency of the laser beam) interferes with the zero order beam from the AOD2 of frequency f_o. The photo detector 1 captures the resulting interference beam of frequency f_B. The photo detector 1 and photo detector 2 are connected to the reference and measuring port of the signal processor respectively.

Experiments

Experiment was carried out in a vibration isolation table using He-Ne laser (632.8nm) in a clean room environment. The beam was scanned on the surface of the rotating disk and the dynamic information (Run Out of disk) was recorded at various scan points.

The resultant displacement output of the signal processor is given by

$$d = \left(\frac{\phi_1}{2\pi} + N_1\right)\frac{c}{2 f_0}$$

where d is the amplitude of vibration, ϕ_1 is the phase angle, N_1 is a integer, c is the velocity of light, f_o is the frequency of the laser beam.
Fig. 4 shows the measured result.

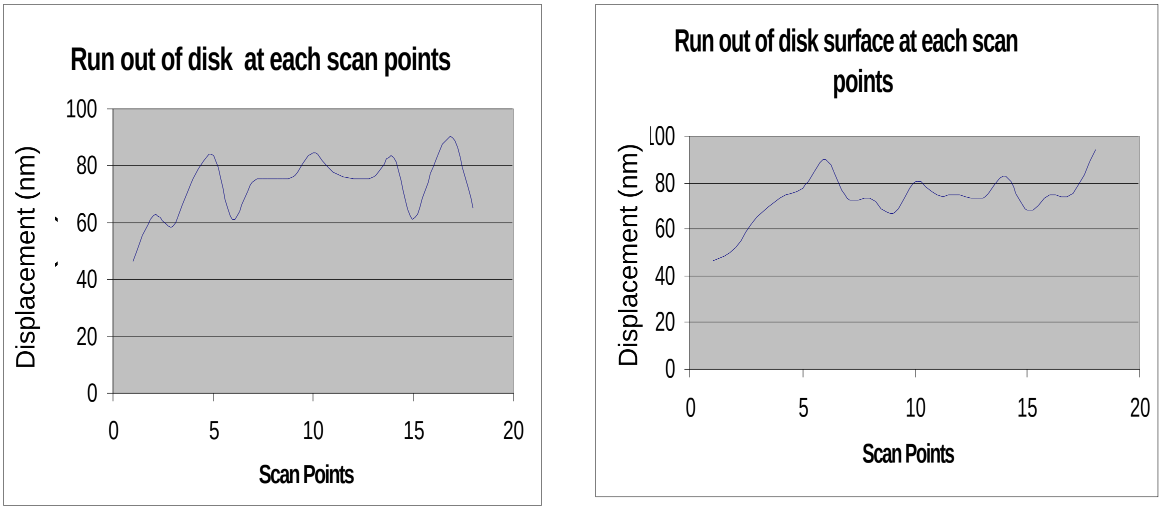

Fig.4 Run out of the disk at different scan point

Conclusion

Since the process applies Acousto optic Deflector, a non-mechanical means of scanning, for scanning the beam it has the following advantages

- High accuracy even when the beam is scanning at high speed.
- The number of resolvable points is about 68,000 point for each of the scanning axis, which is very difficult to be achieved by a mirror driven scanning means.
- It has a very high sweep rate.
- The Acousto Optic scanning mechanism has a very high positioning accuracy and repeatability.

The non-mechanical scanning method finds a wide application in optical storage, hard disk drive and also in MEMS application. The next challenge is the reduction in the spot size of the laser beam, which is limited by the divergence of the laser beam from the laser source.

Reference

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