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A MULTI-CHANNEL PRECISE MEASUREMENT of DYNAMIC PROPERTIES of MOVING OBJECT USING: "LASER DOPPLER DISPLACEMENT METER" TECHNOLOGY and NEW WINDOWS 95/NT SOFTWARE TOOL.

by
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ABSTRACT:
The fast and accurate measurement of dynamic properties of a moving stage like linear motor or a rotary table is possible using
LASER DOPPLER DISPLACEMENT METER.
Dynamic data of displacement are collected at a data rate up to 800 000 data per second while the target is steady or is moving up to 5 meter per second.
The measurement range is up to 100 m with a resolution of 1.2 nm and 1 PPM accuracy and large misalignment tolerance in conjunction with a user friendly windows 95/NT software make it an important tool for the study of dynamic of the motion.

With the introduction of the linear motors become stringent to have the possibility to measure dynamically the position of a stage and it accuracy respect to the command. It is also important to study the behavior of the structures in the dynamic phase of the movement. In general the existing accurate devices that are used for accurate displacement measurement over several meters are doing that statically and the devices that are able to measure the dynamic proprieties do not have the possibility to do it continuously for a long range because they do not have the capability to measure large displacements.

LINEAR ENCODERS

the linear encoder or linear scale is typically an incremental device, on an adequate support that can be glass (up to 3000 mm) or a metal tape (100m) there are a series of lines ruled on it, the lines should be either optically or magnetically detected by a pick up device that have to be carried constantly parallel to the rules. The position is measured counting the number of lines. The numbers of lines vary from 100 to 10 each mm (10 micron to 100 micron pitch) and in general there is also the capacity of extrapolate a number of points between the lines, it varies between 4 to 1024. The direction of the motion is done by a multiple number of detectors spaced of some increments apart. An electronic circuit convert the counts into distance measured.
The accuracy of such devices when used in the field varies between 10 to 100 PPM (10 to 100 micron/m). the difficulty to use such type of devices is to assure

the correct rectilinear positioning of the device and the guiding of the sliding reading head. Such tolerance is in general 0,1 mm or less.
Currently this type of device is largely used on machine tools and the position of the device is chosen during the machine design and the site for the transducer is machined during the machine construction and it is part of the machine. Any addition of such kind of transducer for the machine testing in different position is very difficult or impossible.

INTERFEROMETERS AND VIBROMETERS

Are both very accurate devices based on laser interferometry and specialized in different fields by using different optical schemes.
The interferometer was invented by A. A. Michelson in the late 1881 but was necessary to wait for the invention of the laser to start to have an usable device for metrology. The Michelson interferometer is basically a device that divide the light from a laser source into two equal parts, one is used as reference and the other part is delivered to a target that reflect it back. The reflected beam is mixed to the reference beam into an electro-optic sensor where the pattern of interference is detected. Measuring it is possible to monitor the movement. The laser interferometer is specialized in counting the fringes by means or an amplitude demodulation and zero crossing detector or in phase demodulation, so they are able to estimate the target displacement. The vibrometer is a device that with a slide different scheme and detector type measure the frequency of the target oscillation to easily pick up the dynamic proprieties.

DISPLACEMENT MEASURED BY DOPPLER EFFECT

The LDDM is based on the principles of radar, the Doppler effect and heterodyning. Similar to Doppler radar, a target (here a retroreflector) is illuminated by a laser beam. The light reflected by the retroreflector is frequency-shifted by the motion of the retroreflector. The Doppler frequency shift can be expressed as:

$$f=2fo\ V/c \qquad \text{or} \quad \Delta\phi / 2\pi = 2fo\ \Delta z / c$$

where f and $\Delta\phi$ are the frequency and phase shift, respectively; V and Δz are the velocity and the displacement of the retroreflector, respectively; fo is the frequency of the laser; and c is the speed of light.
A phase detector measure the phase variation, which corresponds to the retroreflector. When the displacement is larger than half wavelength a counter records the total phase change. The total displacement can be expressed as:

$$\Delta Z = c/2fo\ (N+ \phi / 2\pi).$$

A fast Analog to Digital converter is used to read the phase angle and a counter is activated by the half wavelength signal. The values are stored is a 64K couples of Bites RAM memory at the selected clock rate (two bites or 16 bits are necessary to memorize a single point). Each board can have two channel capability and the software can control 4 board with a total of 8 simultaneous channels.

The data are transferred to the computer memory after all the set of data is collected.

APPLICATION OF LDDM AND NEW SOFTWARE

The largest advantages of Laser Doppler Displacement Meter (LDDM) is the large dynamic range that reach 110 dB and the large misalignment tolerance. The system is characterized also by the little dimensions and rugged of the laser head 50 x50 x 208 mm that include all the sensors and the external target mirrors, in general a corner cube with a mass of 1,4 grams for the 6 mm diameter reflector. The measuring range go from 1.2nm to 100m and the target can be steady or can move up to 5m/s and/or vibrate up to 400 KHz. There are several methods to catch data from this device, the simplest is to direct read from a display, or collect them by an RS232 serial interface by a portable personal PC and windows collecting and metrology analysis software or as used in the described experience, by a catch board that can collect 65 000 data at variable rate from 400Hz to 800kHz corresponding to a period of 0,08 sec to 3 minutes. It is possible to take up to 8 synchronized channel at the same time so it is possible to analyze the movement of a rigid body from different angles having multiple information. A simple example is to take two parallel displacement information on the same travel, we have the information of the displacement and the angle of deviation from a straight line, the angle is calculated by the difference of the two displacement divided by the distance of the two parallel beams. Integrating the angle we can have the lateral movement of our device under test respect the straight line done by the laser beams.
The good sensitivity of the sensors allow a lateral misalignment of the beam almost equal to the 95% of the laser beam diameter, the available beam diameter goes from the standard 5 mm to 20 mm that is normally used for very long range application.

PRACTICAL APPLICATIONS

The system was tested measuring the performances of the angular encoder of the VLT very large telescope. Was possible to collect two tangential displacements for an angle of 13 deg on a ring of 7m of diameter . the measurement of the 750 mm displacement was possible with the use of the dual path arrangement of the laser beam, see the photo. The diagrams are showing the acceleration transient of the linear motor with angle displacement, velocity and acceleration.
In the figures is also possible to see the shock wave pendulum that was used to generate and study simple sine waves as well as complicated shock waves

CONCLUSION

The combination of the very sophisticated but easy to use laser interferometer with the self explaining windows 95 software make possible to have an instrument that is usable without a special training because the current existing experience in computer use is fully usable with the maximum efficiency.

New set of performan[...]

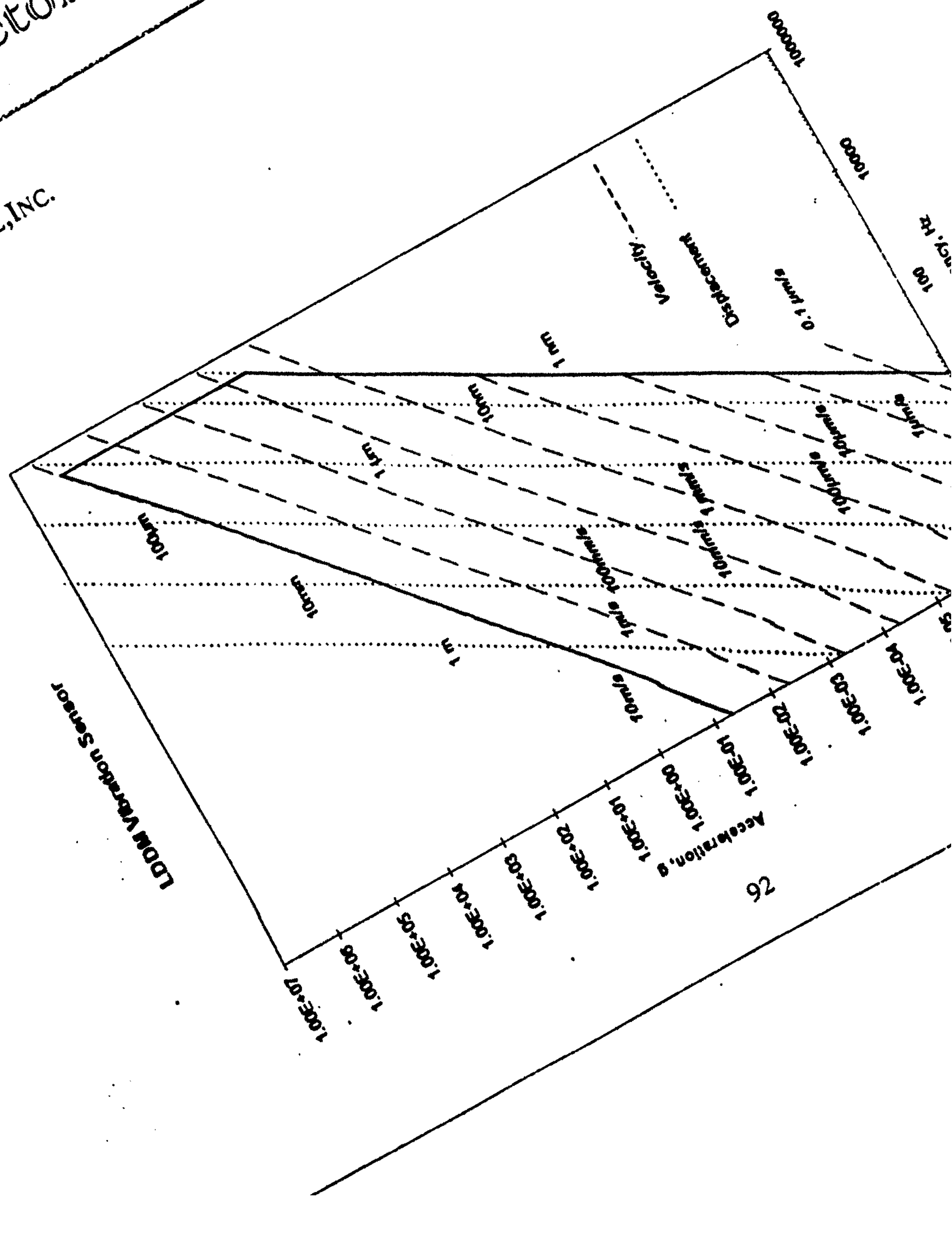
[...]ution	1.2 nm
[...]d	0 - 5 m/s
[...]nge	0 - 50 m
[...]ampling Frequency	390Hz - 800KH
Acceleration	0 to 1 000 000

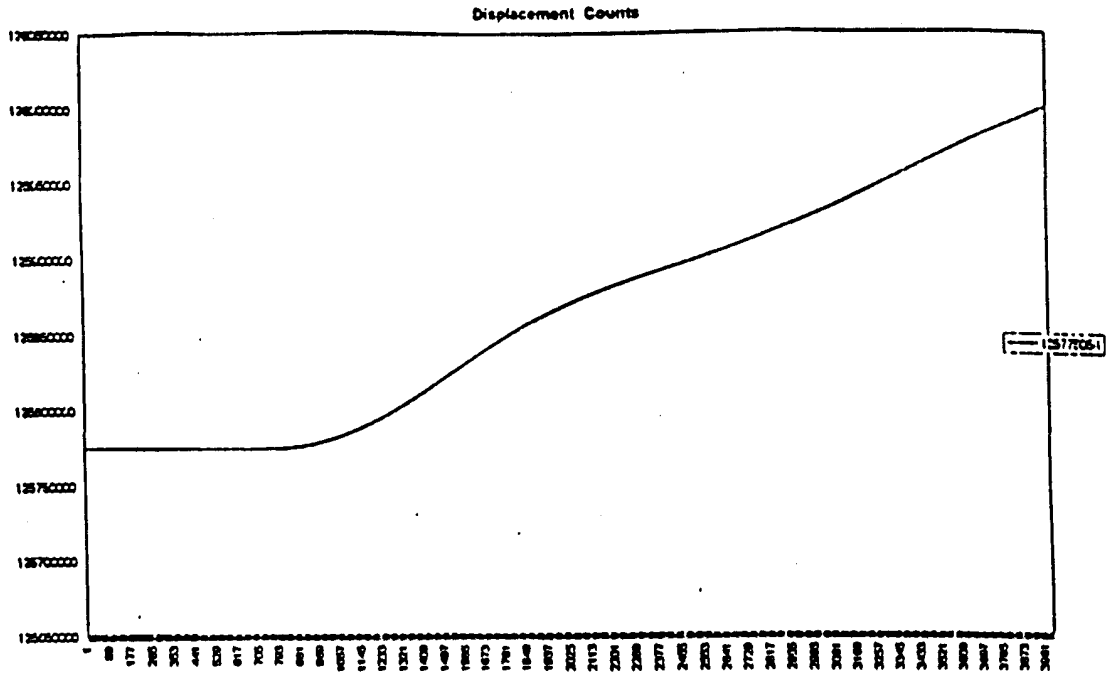
Reflective target :

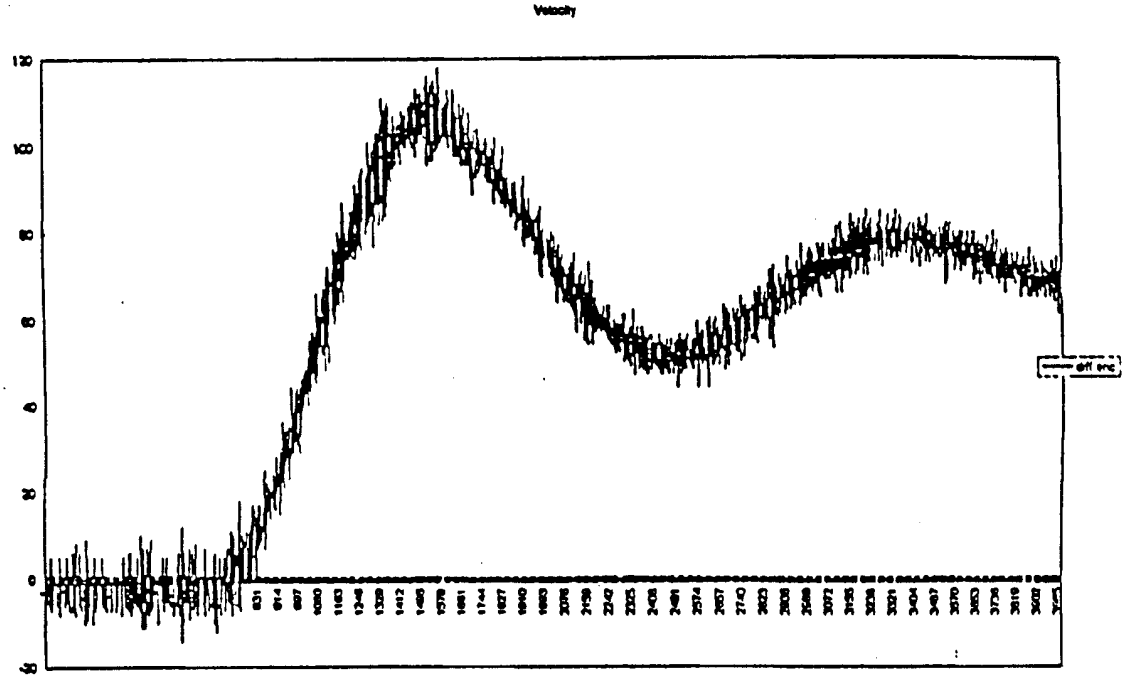
no needs of for short range

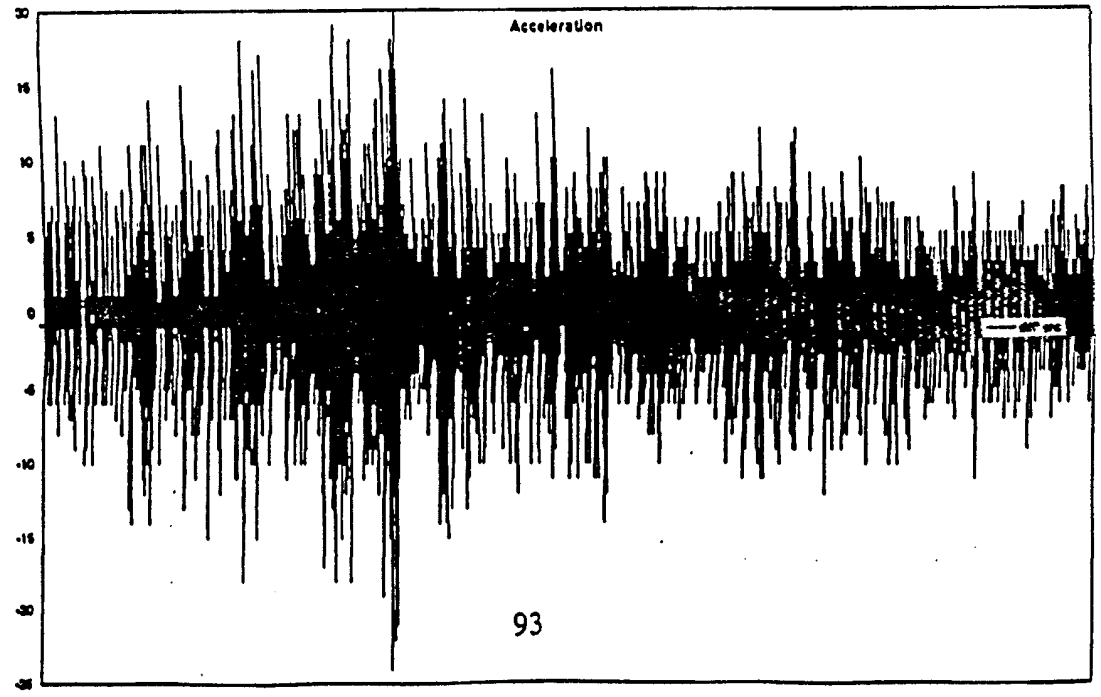
little reflector (2-5 mm) for long rang[...]

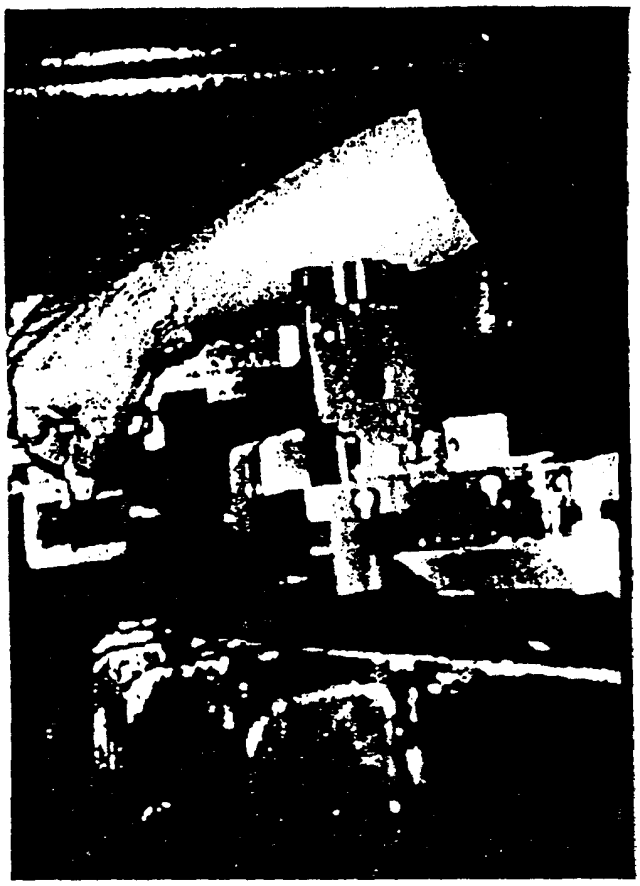
OPTODYNE, INC.



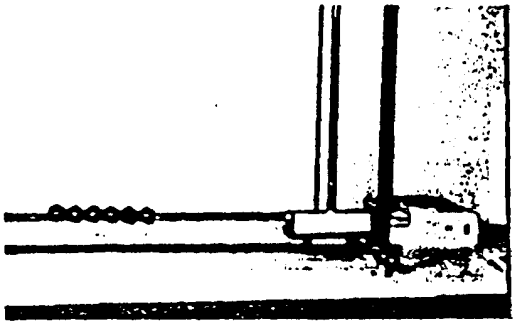

Displacement Counts


Velocity

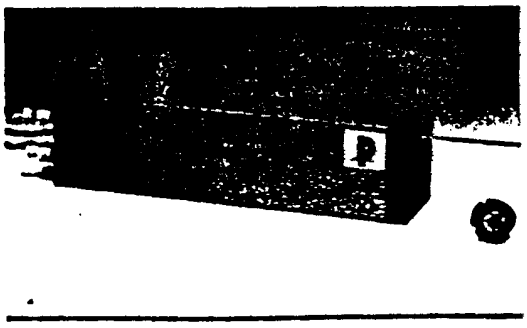

Acceleration



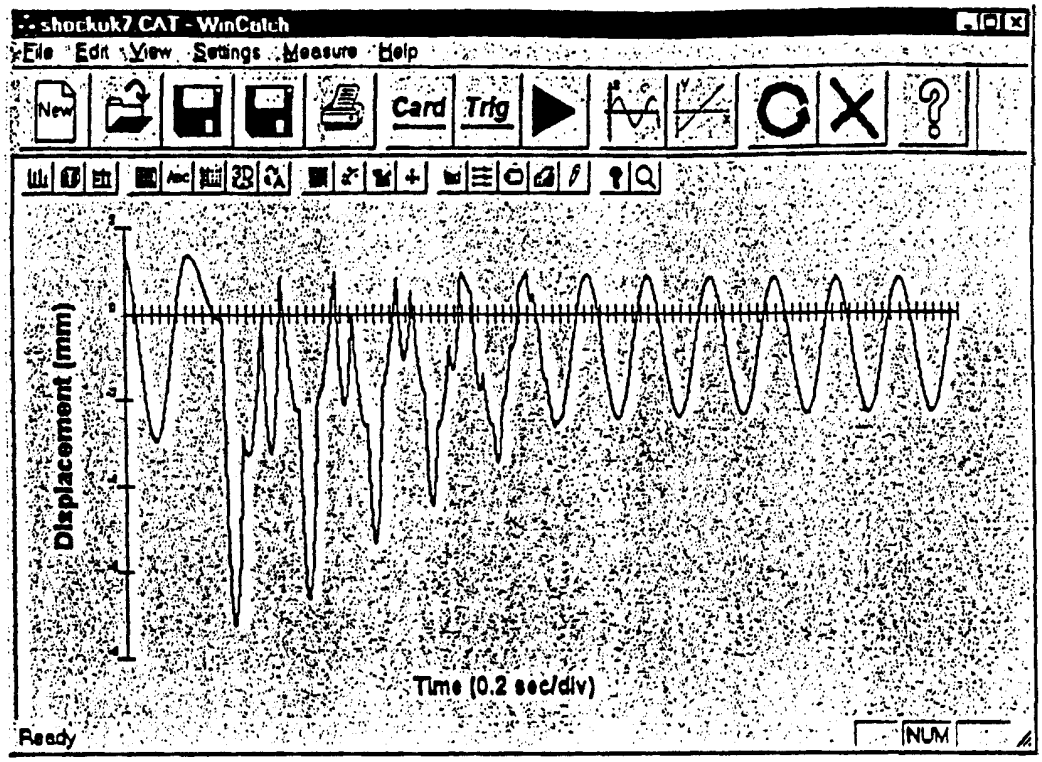
Double path tangential laser arrangement.
It possible to see the laser head on the back of the flat mirror. In front the corner cube retroreflector that is describing a circle in front of the laser.
The operator is tuning the Flat mirror position.



Shoch wave pendulum



Laser head with corner cube retroreflector



Wincatch program display with the view of the shock wave displacement taken with the "shock wave pendulum".
On top of the screens is possible to see the command buttons.
On the screen below the dialog boxes as example of parameter settings.