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Author(s):
Robert D. Day, MST-7
Elfino V. Armijo, MST-7
Peter L. Gobby, MST-7
Douglas J. Hatch, MST-7
Gerald Rivera, MST-7
Leander J. Salzer, MST-7
John D. Townsend, MST-7

MASTER

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Rapid Fabrication and Characterization of Sine Wave Targets

Robert D. Day, Elfino Armijo, Peter Gobby, Douglas Hatch, Gerald Rivera,
Leander Salzer, John Townsend

Los Alamos National Laboratory, PO Box 1663, MS E549, Los Alamos, NM 87545

ABSTRACT

The effect of surface perturbations on Inertial Confinement Fusion target performance is currently being researched at Los Alamos National Laboratory (LANL). These perturbations can cause hydrodynamic instabilities which in turn reduce the targets' yield. To systematically measure the growth of these instabilities requires targets to be produced which have perturbations of a known amplitude and spatial frequency. We have recently assembled hardware onto one of our diamond turning lathes which enables us to machine and measure these sine waves in about 15 minutes. This is a significant reduction in time from the two and one half hours required by the previous method. This paper discusses the hardware, how it works, and how well the system is working for us to produce these targets.

Keywords: precision machining, controlled fusion

INTRODUCTION

Inertial Confinement Fusion (ICF) targets are small, close tolerance, objects whose surface finishes are comparable to those of most metal optics produced in industry. Typical specifications are: sizes of about 0.5 mm, dimensional accuracies of 1 μm, surface finishes of 0.5 nm rms. The reason for such demanding specifications is that manufacturing defects can be amplified as the targets are imploded. If the amplification is too great the implosion becomes unsymmetrical and the target will not ignite.

It is well known that all manufacturing process are imperfect and therefore the parts are imperfect. A systematic investigation into the nature of manufacturing defects and how they influence target performance had not been performed. Therefore it was decided produce targets with known "imperfections" and observe their behavior as the targets are imploded in the laser system. Since the behavior of single mode perturbations (i.e. sine waves) are the simplest to evaluate both theoretically and experimentally, it was decided that a series of cylindrical targets with sine wave perturbations of various amplitudes and angular frequencies needed to be produced for evaluation. A representation of a five mode target is shown in Figure 1.

FABRICATION OF SINGLE MODE CYLINDRICAL TARGETS

Initially these targets were produced by "fly cutting" using the x, z, and rotary axes of a diamond turning lathe. This method was effective however it had some major drawbacks. These were: it was slow (it took about two hours of machining time per target), the set-up was tedious, and it required a genius to program the lathe (who was resident within our group, fortunately). Because of these difficulties an alternative manufacturing method was sought.

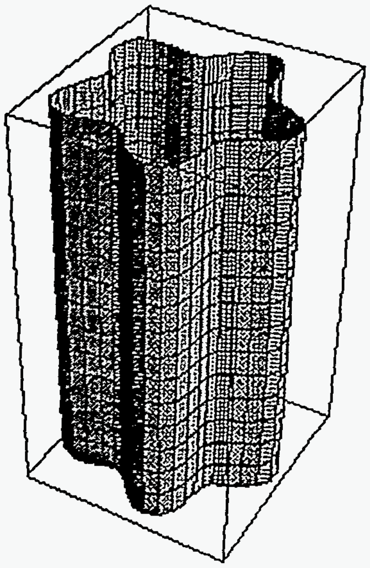

Figure 1 - Drawing of five mode target

The answer to the production problem was a fast tool servo (FTS). The FTS consists of a device that can move the cutting tool very rapidly and very precisely. With such a device the tool, if timed to the spindle of the lathe, can machine the sine waves onto the cylinder's surface as rapidly as a normal unperturbed cylinder can be produced. This could reduce the machining time from hours to minutes. Therefore a contract was written to North Carolina State University (NCSU) to produce such a device for us. The specifications for this device were:

1) it needed a 15 KHz bandwidth,
2) it needed a maximum travel of 5 μm,
3) it must have an rms. noise level of 5 nm, and
4) it must be controlled through our lathe's controller.

The dilemma we faced was that NCSU was due to deliver their FTS in a year and a half and we needed an FTS today! So we decided to build a lower performance FTS, using hardware that was available at LANL, for use until the higher performance system was available. We refer to our interim system as and analog FTS (as opposed to the computer controlled, i.e. digital, FTS that NCSU was building). (NCSU has just delivered this FTS to us and the device has met or exceeded these specifications[1].)

DESIGN AND IMPLEMENTATION OF THE ANALOG FTS

Fortunately, the only two angular frequencies that the target designers were interested in were 10 and 14 waves per revolution, i.e. modes 10 and 14. So our system did not have to be very flexible in that dimension. The designers did require many different amplitudes, but it was thought that this could be accomplished simply by changing gains with a potentiometer. So we felt that a system could be built relatively easily. The concept was this:

A) Make a "cam" that has two tracks on it that mounts to the spindle of our lathe. The first track has mode 10 sine waves on it and the other has mode 14 on it.

B) Read the amplitude changes on the cam with a non contact, high bandwidth, high resolution, high accuracy displacement transducer such as a capacitance gauge. This provides an sine wave voltage signal of the proper mode number, depending upon the track that the gauge is reading, that is synchronized to the spindle.

C) Feed the capacitance gauge's signal into a high voltage amplifier that drives a piezoelectric translator which moves the tool. Therefore the tool's oscillating motion will be synchronized to the spindle with the number of modes per revolution.

This design is shown schematically in Figure 2.

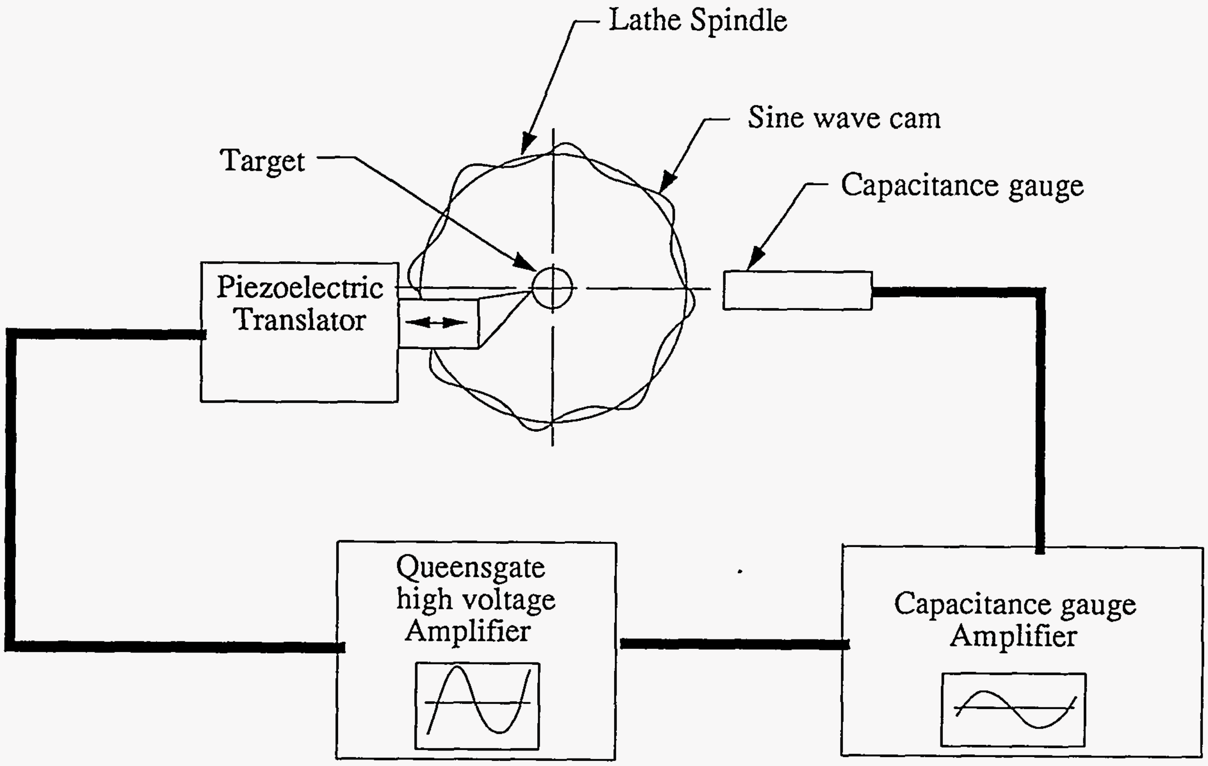

Figure 2 - Schematic of analog FTS.

The capacitance gauge that was available had a maximum reading range of 0.25 mm. Therefore the sine waves on the cam had a maximum peak-to-valley change of 0.125 mm. This cam was machined using a numerically controlled milling machine.

A piezoelectric translator was available to us that was made by Queensgate Instruments[2]. This translator was particularly nice because it was operated by a control circuit that obtained position feedback information from a capacitance gauge that was imbedded within the piezoelectric stack. This arrangement linearized the output from the piezoelectric stack and gave us very nice position feedback control. The translator could easily machine sine waves with peak-to-valley amplitudes of 3 µm at a frequency of 25 Hz with a position noise of 6nm rms.

The peak-to-valley amplitude of the desired sine waves ranged from 0.5 µm to 3 µm. To adjust the translator to give us the desired amplitude a potentiometer was place in the circuit between the signal coming from the capacitance gauge reading the cam and the Queensgate high voltage amplifier. The maximum motion range could be read from a meter on the Queensgate amplifier as the spindle was turned at 1 rpm.

Once the amplitude adjustment was made, the Queensgate amplifier was turned of and the cylinder was machined to it's maximum diameter. When this step was completed the Queensgate amplifier was turned on which started the tool oscillating at the desired amplitude and frequency. As the tool fed down the cylinder the sine waves were produced on the surface. This process took about 5 minutes. So the production time was indeed reduced from 2 hours to 5 minutes per target.

MEASUREMENT OF SINE WAVE PERTURBATIONS

After producing the sine waves the experimenters needed to know what was actually produced so this information could be used to compare theoretical predictions to experimental data. The target material was polystyrene which is quite soft therefore our method of measurement needed to be very gentle. Interferometric methods were first attempted but only a portion of the cylinder could be measured at a time. This meant that numerous data sets had to be measured and pieced together to obtain a complete "picture" of the surface. This was very difficult to accomplish. It was then decided to trace the target with an air bearing linear variable differential transformer (LVDT). The air bearing LVDT gave us a very light gauging force, very high resolution and a very linear voltage vs. displacement signal. Since the targets were so small (0.5 mm mean diameter), the measuring stylus consisted of a 100 μm diameter glass sphere that was glued to a glass shaft that mounted to the LVDT. A great advantage of this measurement method was it could be made on the lathe immediately after the target was produced. This, of course, gave us the opportunity to remachine the target, if necessary, without having to relocate the target and the cutting tool to within a few hundred nanometers. Interferometic measurements taken of the surface after tracing the part showed no damage to the surface caused by the stylus.

The measurement procedure consisted of:

1) mounting the LVDT to the correct position with the aid of an optical microscope mounted to the lathe,

2) calibrating the LVDT using the lathe's laser interferometric feedback system as the reference,

3) rotating the lathe spindle at 1 rpm, and

4) recording the LVDT signal on a digital oscilloscope.

The stored data was processed by the experimenters and used to compare to the theoretical predictions. The measurement of the targets was usually performed in less than 10 minutes. An example of the measurement data is shown in Figure 3 for a mode 10 target with 2 μm peak-to-valley amplitudes.

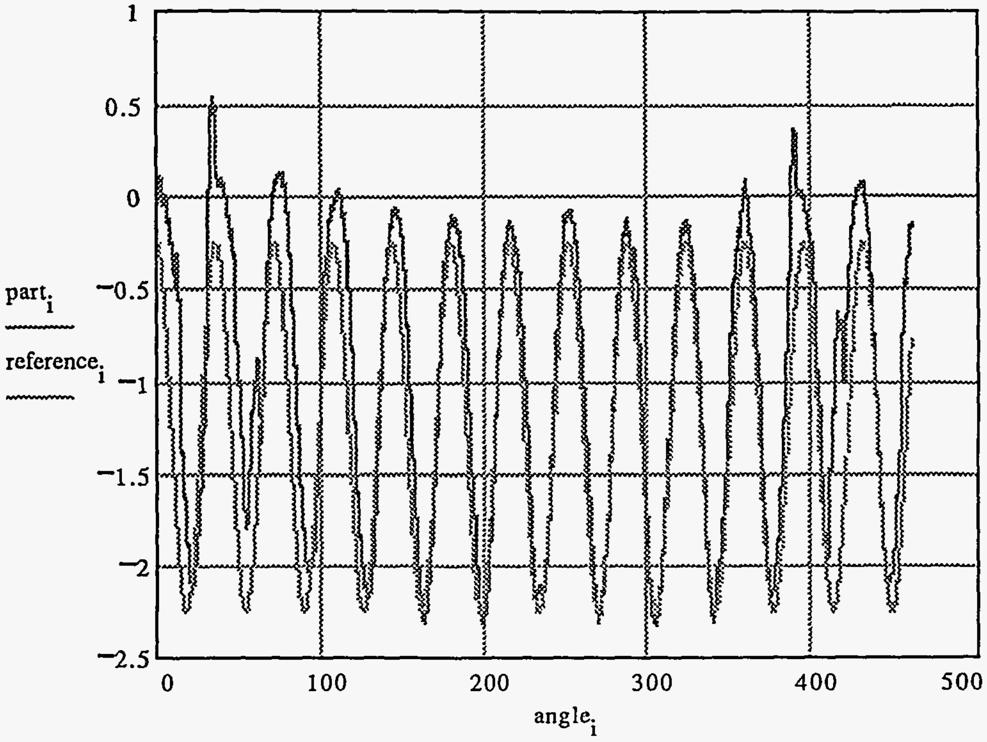

Figure 3 - Plot of radius change as a function of angle for a mode 10 target with 2 µm peak-to-valley theoretical amplitudes. The units on the ordinate are in µm. The solid line, marked part_i, is the trace of the actual target and the dotted line, marked reference_i, is a plot of an ideal target. The target was traced for a little more than one rotation to assure that one rotation of data was captured.

It can be seen in figure 3 that the sine waves produced on the target match the desired sine waves very well. There do appear to be low frequency discrepancies between the reference and part traces, however. These discrepancies arise from the location of the LVDT probe when the part was traced. The LVDT was placed on the opposite side of the part from the cutting tool. This has the effect of magnifying the spindle radial error, when measuring the part, in accord with equation (1).

$$e_{tot}^{\theta} = e_{part}^{\theta} + e_{spindle}^{\theta+180} \qquad (1)$$

Where θ is the particular angular location where the part is being measured, e_{tot}^{θ} is the total spindle radial error effect that is included in the LVDT's measurement of the part, e_{part}^{θ} is the error on the part that is caused by the spindle's radial error motion, and $e_{spindle}^{\theta+180}$ is the spindle error motion that occurs when the spindle is rotated 180 degrees away from where the tool was when the part was being made (this is the position that the spindle is in when the part is being measured). The characteristic radial error pattern, as a function of angle, is a two lobed pattern with a peak-to-valley amplitude of about 150 nm. For this pattern a total low frequency component in the measured data of 300 nm would be expected. This is the case for the data displayed in figure 3.

CONCLUSIONS

The analog FTS has reduced the machining and inspection time per target for cylindrical sine wave targets from 2 hours to 5 minutes. These targets can also be easily and accurately characterized within 10 minutes after fabrication on the same lathe that was used to machine them. The system has been very effectively used for about one year. An excellent description of the results of these experiments are given in reference 3.

ACKNOWLEDGEMENTS

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