Manufacturing of High Precision Leveling Rods

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Summary

In this paper we describe the process of manufacturing and calibration of high precision leveling rods. At NEDO in cooperation with the University of Karlsruhe, Germany, a new method of manufacturing high precision leveling rods has been developed. The basic idea is to use a high energy pulsed CO_2 laser source to generate markings on the surface of a steel tape. Therefore, the tapes are first sprayed black , then afterwards sprayed yellow so that only yellow is visible on the surface. The high energy laser is used to remove yellow color in those regions which are expected to be marked as black, either for barcode or standard scales. To enable precise positioning of the rod we use a high precision laser based calibration system. This new manufacturing method results in very small random errors of less than ±0.007 mm. Permanent calibration of our leveling rods at the Technical University of Munich, Germany, certifies a very small thermal length extension coefficient.

1 HIGH PRECISION SCALES

1.1 History

Until the late 70's, leveling rods were manufactured in two different ways: (1) using a mask made of invar steel to spray a scale on a steel tape and (2) using a milling machine to engrave the scale on the rod. Both methods were not able to fulfill increasing precision requirements. That was the starting point for NEDO to establish a new method of producing high precision leveling rods.

1.2 Overview

Based on a calibration technique described in [3], NEDO developed in cooperation with the University of Karlsruhe a manufacturing process for high precision leveling rods. A tape made of invar steel with a small thermal length extension coefficient ($\alpha \leq 1 \cdot 10^{-6} \cdot K^{-1}$) is first sprayed black and then yellow on top. This tape is moved along a fixed unit which consists of a pulsed high energy CO_2 laser and an optical system consisting of a lens and a mask (see fig. 1). With the high energy laser, parts of the thin top color layer (yellow) can be removed, so that the underlaying layer (black) becomes visible. Therefore the laser is formed by a mask and focused by a lens. To control the CO_2 laser pulses, a high precision laser based calibration system [3] is used. This allows a high accuracy of the manufactured scales. A flexible software interface implemented in the PC based control system allows flexible production of both, standard and barcode scales. With the help of an electro-optical microscope [3] we are able to calibrate our scales for the purpose of a quality control system based on ISO 9001. NEDO is the only company worldwide manufacturing leveling rods of such a high accuracy and quality.

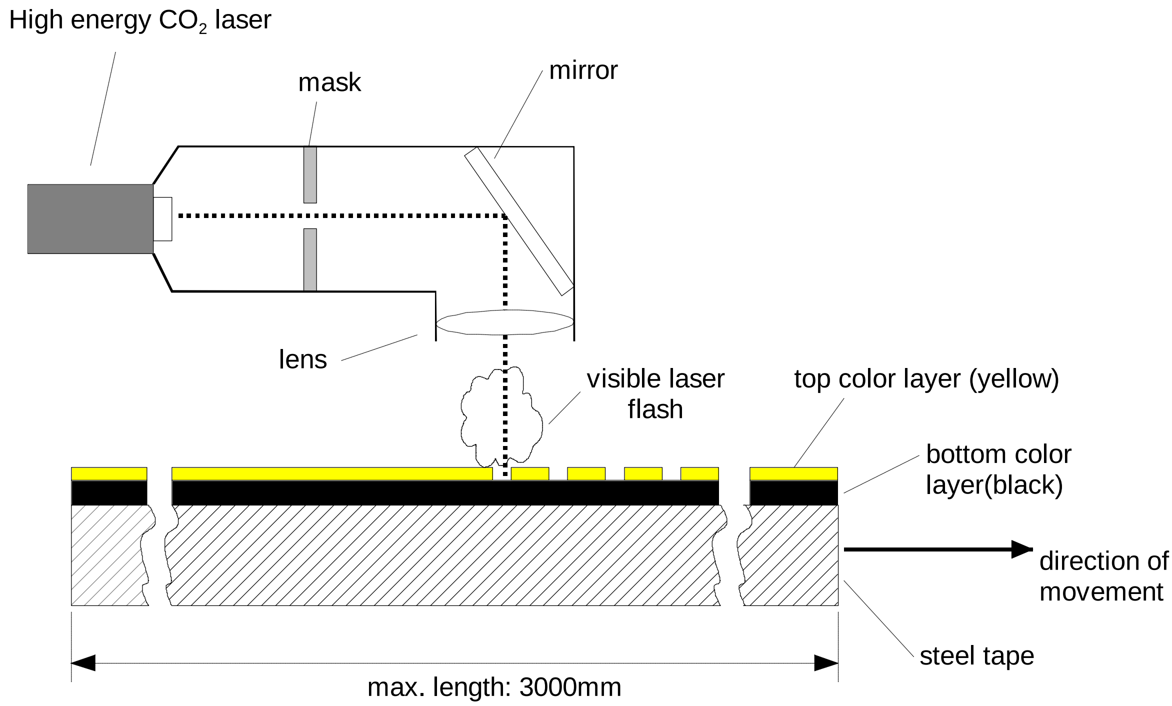

fig 1: principle of the manufacturing process

1.3 Production method

During the process of manufacturing (see fig. 2), a steel tape is fixed on a movable unit which passes along a high energy CO_2 laser at a constant speed *v*. The distance *d*, measured by a very high precision laser based calibrator is sent via the interferometer control unit to the PC based control system. The computer compares this information with formerly calculated positions where the CO_2 laser has to be activated. If both values match, the computer sends one puls to the CO_2 laser.

Basic idea of this new method was a procedure known from simple marking tasks used in the production of electronic components and food packaging. In these applications, a high energy CO_2 laser is used to mark the products with their type or the 'best before' date. Instead of using masks for simply writing text on a surface NEDO analyzed these laser systems with the question if it is also possible to use such as laser for high precision marking tasks. First trials showed, that the lens used in the optical path of these lasers caused a distortion which required much more complex masks than initially planned because these masks had to correct the distortions. Another difficulty was to find best parameters for the CO_2 laser like energy and high voltage level. Lots of experiments were necessary to reach this goal. This problem had to be discussed in conjunction with the type of colors used on the steel tape (see fig. 1). We found, that the yellow color on top showed best optical characteristics. Finally we had to decide, whether to stop the movement of the rod at each position where a laser pulse has to remove yellow color or if it is also possible to keep the steel tape moving at a constant speed. The first possibility would require a very precise positioning of the steel tape and the movable unit on which it is mounted. This seemed to be very difficult because we would have to take in account all the dynamic aspects of the whole system. On the other hand, the timing aspects of the computer based control system seemed to be solvable with a standard computer available in the early 80's. The second possibility (keeping the unit moving at a constant speed) required a very powerful control system which has to interact under realtime conditions. But on the other hand, a precise positioning of the moving unit wouldn't be necessary. A lot of experiments showed us, that a solution based on the second version brought better results e.g. a higher precision. The powerful control system which is necessary for this solution is described in the next paragraph.

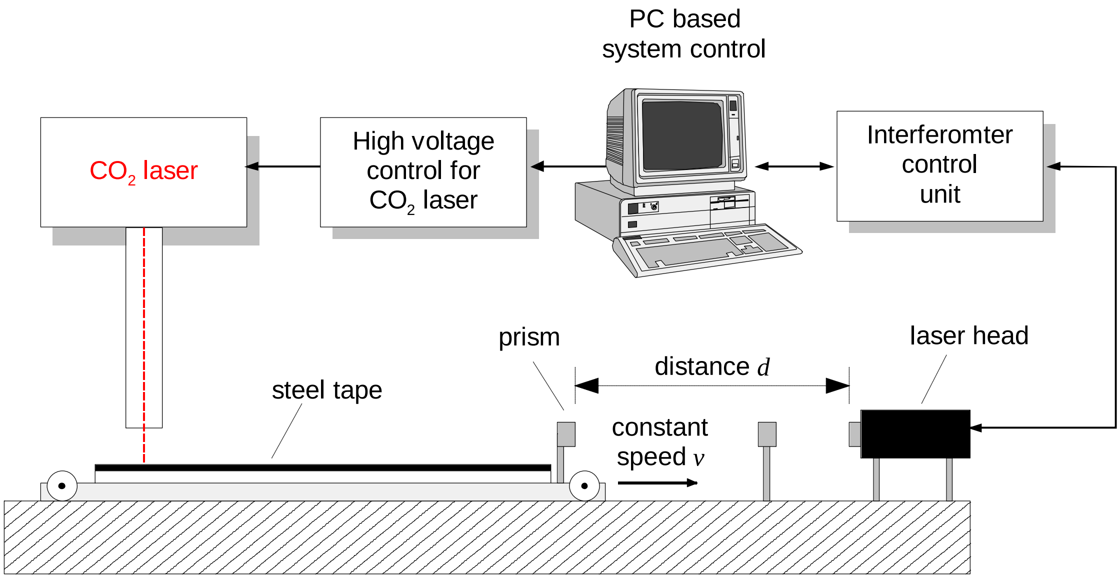

fig. 2: integration of the control structure in the manufacturing process

1.4 Control system

Control of such a complex system described above requires a powerful control system. In the beginning of this manufacturing process, we started with a Commodore CBM4000 - a 6502 processor based system running at 1 MHz using a very simple and small operating system. The poor computing power of this system required complex additional control hardware which was designed in cooperation with university of Karlsruhe.

Meanwhile, processing power of today's computers is high enough and we have a control system based on a Pentium processor. Most of the tasks which were implemented initially in hardware are now implemented in software and allow a flexible adaptation to new scaletypes. The fact that the CO_2 laser is a pulsed type requires a little bit more complex software. In case of manufacturing standard scales (1cm), the software calculates those positions where a single pulse must be generated to trigger the CO_2 laser. Much more effort is necessary to generate trigger pulses for barcode scales. Here we have the problem, that a large black area has to be divided into several single pulses. Based on a fixed width of a single shot, this results in a sequence of shots which have to overlap a little bit to guarantee that no yellow color is left (see fig. 3). At a first glance this seems to be a rather simple task but taking in account all requirements, the solution gets a bit more complex. The most important fact is, that we have to ensure a minimum recovery time between two laser pulses to ensure a perfect function of the CO_2 laser system (see fig .3). If the overlapping of two single shots is too large (based on a constant speed v of the steel tape), we will probably get a violation of the recovery time. Another problem we have to focus on is the fact, that we have to work during a manufacturing cycle with only one mask having a fixed width. This requires that all black areas of a barcode scale have to be partitioned into several elements having a width of this single mask. To fulfill this requirement, we get different overlappings of the single shots depending on the width of a black area. To fulfill the requirement of the minimum recovery time we have two possibilities: (1) adjusting the width of the mask and (2) choosing a speed *v* which ensures no violation of the recovery time. Both parameters can only be varied in small amounts. (1) Increasing the size of our mask will result in an inadequate energy density of the laser flash which wouldn't be high enough to remove the yellow color from the top layer. Decreasing the size of our mask will result in an energy density which is probably too high thus destroying underlaying black color layers. (2) Decreasing the speed *v* will probably result in a discontinuous movement thus adding errors to the scales. Finally for each type of barcode we are producing we had to optimize all of these parameters to get best results.

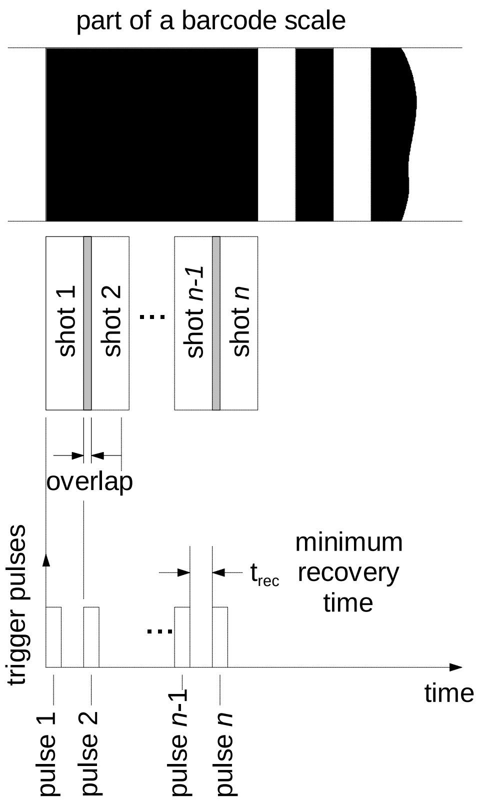

fig 3: dividing a barcode scale into several single shots

1.5 Software

To allow production of different types of scales, we developed a control software which divides generating of control data in two steps. In a first step, a barcode scale e.g. is taken and divided into several single shots fulfilling all requirements as discussed in the previous chapter. As a result a list is generated containing all positions where the CO_2 laser has to be activated. This step allows us to generate a scale-independent data format which allows handling of any kind of scale in an easy to use style. A list as described above can contain production data of both, barcode and standard scales. In a second step this list is read by the software which controls the entire production process, and generates trigger pulses for the CO_2 laser. Also the calibration process is based on this software structure: estimated marking positions are read from a list and compared with the real positions detected by the electro-optical microscope.

1.6 Accuracy

One of the most important questions concerning the manufacturing of high precision scales is their accuracy. Based on the new production method described above, we have random errors of less than ±0.007 mm and a scale factor error of less than 1.2 ppm. To ensure a high level of quality we use an electro-optical microscope [3] for the calibration of our tapes. With its help we are able to detect error sources immediately.

In the last few years, calibration of complete systems (e.g. a leveling rod consisting of an invar steel tape and an aluminum body) has become more and more important [4, 1]. Therefore at Technical University of Munich (TUM) a calibration system was developed which allows calibration of complete leveling rods under changing atmospheric conditions [2]. By permanent calibration of our leveling rods at TUM, we are able to ensure a perfect thermal behavior of our leveling rods. Fig. 4 shows the thermal length extension coefficient of one of our leveling rods. The graph shows the behavior of the rod by applying different temperatures (30° → 0° → 20° → 40° → 10°) to it.

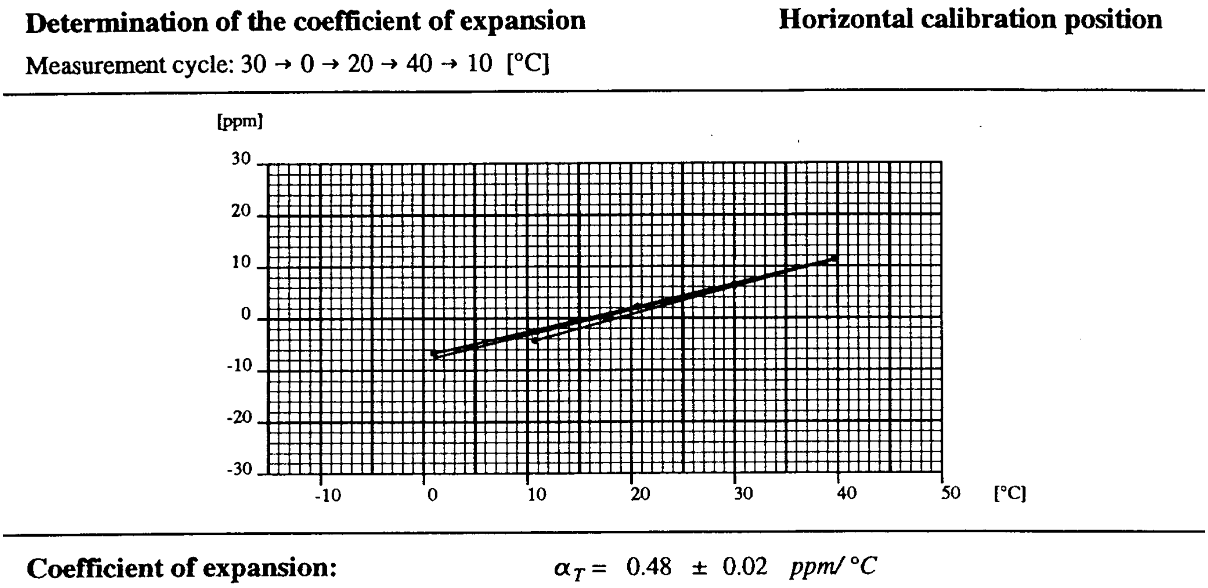

fig. 3: thermal behavior of a leveling rod

2 ASSEMBLING OF THE RODS

In the previous chapter we described the manufacturing of high precision scales based on a new method using a pulsed high energy CO_2 laser and a high precision calibration system. After this manufacturing step, the tapes and the aluminum body of the leveling rods are assembled together. To stabilize the steel tape within the body of the rod, springs are used which fix the steel tapes at a force of 30N. This requires that also during manufacturing of the scales the steel tapes are fixed at the same force onto the moving unit of our new CO_2 laser based engraving machine. For the overall accuracy of our leveling rods it is also important to ensure a right angle between the foot and the body of the rods. To fulfill this requirement we developed a set of tools which allows perfect assembling of foot and body.

3 FUTURE TRENDS

At the beginning of 1998 we established a quality control system based on IOS9001 which requires permanent quality control of our products. As mentioned in chapter 1.6, we use an electro-optical microscope [3]. It was initially designed for calibration of standard scales (1 and ½ cm scales). By adding new scales to our production line, we found that this microscope is not flexible enough because it only allows detection of edges. For the purpose of permanent quality control we are forced to establish a more powerful image processing tool. Currently we are working on this new system which will also be used to detect misplaced and inadequate laser shots.

4 SUMMARY

In cooperation with external partners, NEDO developed a manufacturing process for high precision leveling rods using a pulsed high energy CO_2 laser and a high precision calibration system. Based on a powerful control system we are able to produce both, standard and barcode scales at a very high accuracy with random errors less than ±0.007mm. Permanent calibration of our rods certify an excellent thermal behavior. Currently we are working on a CCD based image processing tool, for further improvement of our quality.

References

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