4D-LASER SCANNING FOLLOWED
BY
INTERNAL COMPUTER MODEL GENERATION

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ABSTRACT:

A 4D-laser mapper has been developed, which samples synchronously Cartesian coordinates with sub millimeter accuracy and the laser intensity reflected from the target's surface. The array of point measurements data are processed by a program module so that the geometry of the object's surface is described. These transformed data can well be used by normed interfaces e.g. IGES and VDAFS and linked to CAD/CAM-system for further processing. By imploying the 4D-laser mapper and the special post processing software the process from carrying out the measurement to storing valid CAD/CAM-data of any object lasts only minutes.

The 4D-laser mapper and the new program module will be presented. Typical measurement and manufacturing results will be shown and discussed with respect to application in CAD/CAM.

KEYWORDS: Laser Mapper, CW Semiconductor Laser, 3D-Measurements, 3D-Reconstruction, Dublicating Milling Machine, Sculptured Surfaces, CAD/CAM/CAP/CAQ

1. INTRODUCTION

The rapid changing market and the steadily raising quality requirements demand very flexible and fast process and quality control loops. This is important especially regarding the improvement of quality standards new and advanced measurement and manufacturing strategies must be developed. Flexible, high precision and robust sensors are required for the registration of measured values. These devices should operate directly at the manufacturing machine and should be linked with Computer Aided Design (CAD) / Computer Aided Manufacturing (CAM) systems by a well defined hard and software interface, in order to obtain a direct connection to higher level Computer Integrated Manufacturing (CIM) systems. Only in this case universitily of the quality control loop could be improved drastically, so that the manufacturing loop could be accelerated and rationalized. This would result in reduced manufacturing costs and new products could be delivered on the market in shorter intervals.

Today non-contacting and contacting (tactile) sensors are used in the production measuring technique of the machine-tool and molding industry (s. fig. 1-1). The non-contacting measuring systems can be classified in optical and acoustical methods. If the measurement is carried out by optical means, laser triangulation, holography, interferometry or photogrammetrical methods are employed. Acoustical range measurement are re-

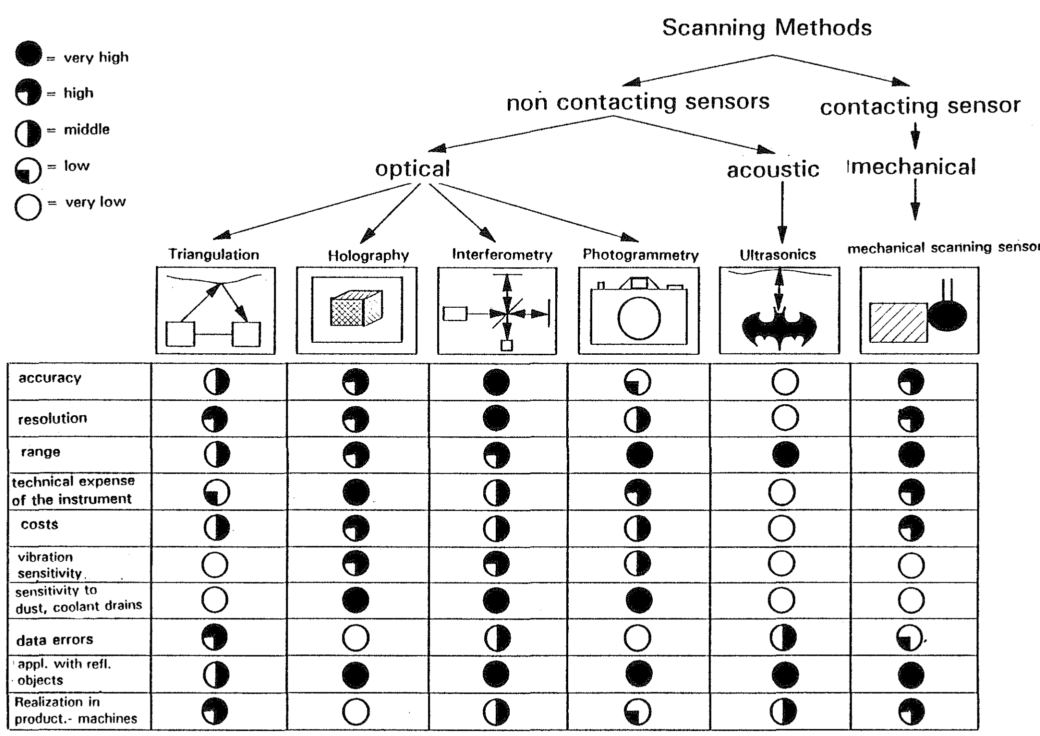

Fig. 1-1: Overview of Current Digitizing Methods

alized by ultrasonic sounding. Due to its long wavelength only a poor geometrical resolution can be achieved with todays ultrasonic technology which is not applicable in molding industry.

Regarding the state of the art in digitizing free-form surfaces the tactile sensors are the most advanced and mostly used measurement systems. The very severe disadvantages are that the measurement result is distorted by friction and drifting forces effects and that only low sampling rates can be realized. Due to the relative long measuring time the digitization of large objects is very time consuming and therefore in many cases impractical in industrial measurement applications. In addition processing problems of the digitized data rise if the actual tool has different size and geometry with respect to the sensing stylus. Most tactile sensors available on the market have got their own control, can be easily implemented in production systems and have standard interfaces (e.g. DEMIS, Verein Deutscher Automobilhersteller Freiformflächen-Schnittstelle (VDAFS) etc.) to higher level CAD/CAM systems.

In the following a new non-contacting optical four dimensional measurement system will be described. It is a so called 4D-Laser-Mapper (4D-LM) and ensures short measurement times and versatility which is especially required in molding industry. Its measurement data is processed by a new software module. This module is optimized with respect to 4D-LM. Using 4D-LM and the advanced postprocessing module the process from carrying out the object lasts only minutes. Finally it will be shown that the manufacturing loop, which comprises survey of objects, the generation of valid CAD/CAM data and at last CNC data for manufacturing the workpiece, can be closed effectively.

2. 4D-LASER-MAPPER

The 4D-Laser-Mapper (4D-LM) was developed at the Institute of Navigation at the University in Stuttgart (INS). It digitizes contours of objects by a scanning remote sensing laser beam and its design was optimized to the requirements of the machine-tool and molding industry. It achieves high sampling rates with accuracies in the submillimeter range and can be easily coupled with CNC-machines and handling devices (s. fig. 2-1). Therefore it is possible to control and synchronize on-line the 4D-LM with the control of the production machine.

The 4D-LM belongs to the family of the flyingspot measurement systems, because the illumination spot and the instantaneous receiving field of view is synchronously moved across the object's surface by an opto-mechanical deflection device which is ealized by two galvanometer scanners (s. fig. 2-2). The object's surface is three dimensionally digitized by measuring in each illumination point - in the following also called picture element or pixel - the slant range R between the 4D-LM aperture and the illuminated point on the target's surface. As the deflection angles α_x and α_y of the two galvanometer scanners are known, Cartesian coordinates can be calculated straight forward by using a special raytracing algorithm which regards improper adjustments in the opto-mechanical setup of 4D-LM. In addition to the slant range R, the intensity I of the reflected laser light upon the object's surface is sampled. Therefore a four dimensional vector (4D) with coordinates (x, y, z, I) is stored for each pixel on a hard disc.

The slant range R is obtained by modulating the optical power of the laser with a high frequency signal of 313 MHz. Using a semiconductor laser this can easily be achieved by modulating the drive current of the laser diode. This is also known as direct modulation. The modulated laser light is collimated so that a spot with a diameter of about 2 mm is illuminated upon the target's surface. This light spot is located within the instantaneous field of view of the receiving optic which imaged the laser spot on an optical detector. The optical detector should have a high responsivity and should respond very fast. Therefore an avalanche photodiode (APD) with large bandwidth was selected. The APD reproduces directly the 313 MHz signal out of the received optical signal. As the received signal travels two times R (s. fig. 2-3), it is received delayed by a delay time t_L:

$$t_L = \frac{2 \bullet R}{c} \tag{1}$$

if c is the speed of light. This delay causes that the transmitted and received signal have a phase difference ϕ of

$$2\pi \bullet f \bullet t_L = \phi \tag{2}$$

if f is the frequency of the modulation signal. In our case is f = 313 MHz. This phase difference is electronically measured (s. fig. 2-1) using analogue technique. This analogue phase value is converted into digital format by an analogue to digital converter, so that it can be transmitted via the PC-bus to a microprocessor which calculates the slant range R by using equations (1) and (2):

$$R = \frac{1}{4\pi f} \bullet c \bullet \phi \tag{3}$$

As the 4D-LM should be used in industry without special laser safty precautions the transmitted optical power must be reduced to a minimum regarding the high collimation of the laser beam. However, a limited laser power means also limitation for the achievable accuracy of the range measurement σ_R, which is a function of the signal-to-noise ratio SNR and the frequency of the measuring tone:

$$\sigma_R = \frac{c}{4\pi f} \bullet \frac{1}{\sqrt{SNR}} \tag{4}$$

The SNR is determined by the magnitude of the received optical power and the bandwidth of the measurement system. Large bandwidth means a short measurement time.

As on one hand the optical power must be limited and on the other hand the accuracy should be as high as possible a trade off in the 4D-LM's design must be carried. A design study showed that a 4D-LM with the technical specifications listed in table 2-1 is a relative optimum for the application in machine-tool and molding industry.

table 2-1: Technical Data of 4D-LM

Laser Power	0.5 mW
Wavelength	670 nm
Inst. Field of View (IFOV)	0.1° (1 mm transmitting aperture)
Total Field of View (FOV), variable	max. 30°x30°
Receiving Apertur	24 mm
Scanning Method	2-dim. Linescan
Number of Pixels	400x400 or 800x800
Range	max. 2 m
Ranging Accuracy	0.1 mm (diffuse reflecting target with 60% reflectivity, distance 1 m
Ranging Tones	10 MHz, 313 MHz
Measurement Rate	2 kHz (using one tone), 800 Hz (using two tones)
Scanning Time for 200x200 pixels	20 sec

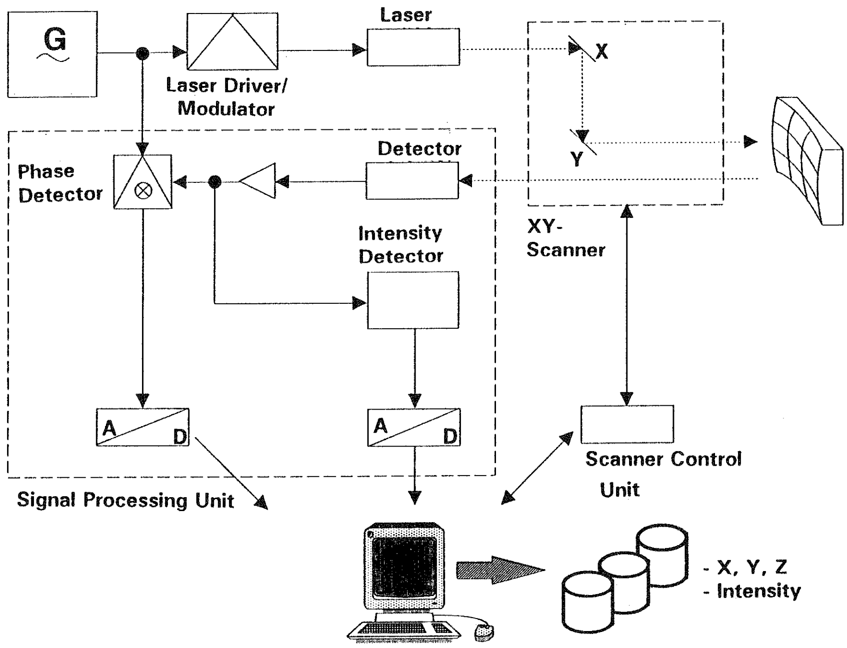

Fig. 2-1: Blockdiagram of the 4D-LM

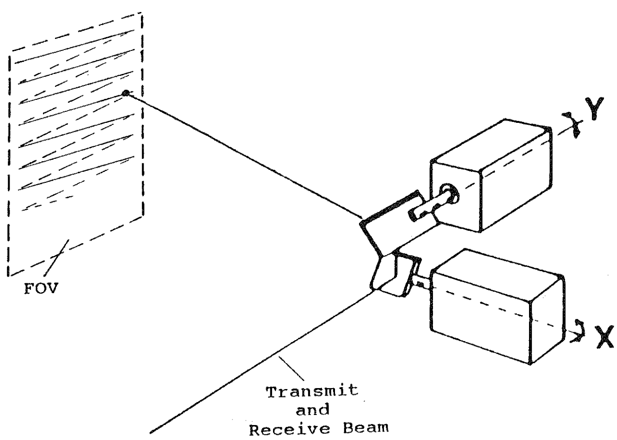

Fig. 2-2: Opto-Mechanical Deflection Unit

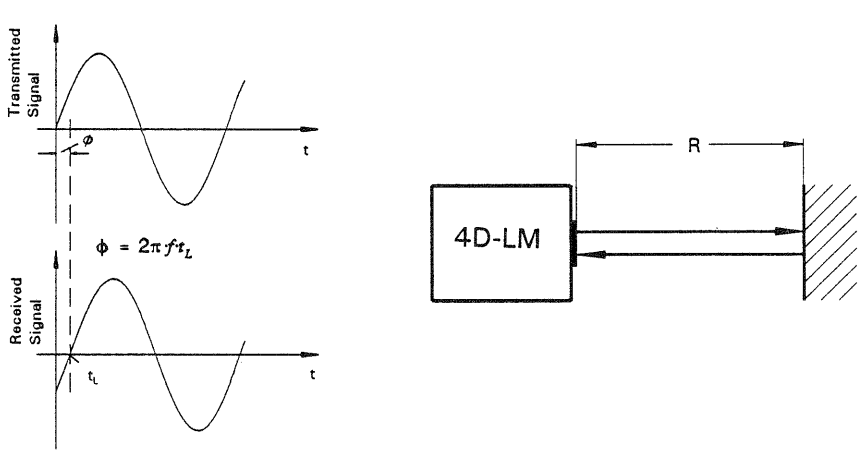

Fig. 2-3: Phase Difference Range Measurement

This system complies with laser safty class II, because a visible semiconductor laser is used. With reference to the data in table 2-1 the ranging performance can be calculated. Assuming distances to the targets' surfaces from the 4D-LM's output of 0.5 m and 1.0 m respectively the maximum possible standard deviation of a single shot measurement as a function of the reflectivity of the target is plotted in fig. 2-4. It was presumed that the target is a Lambertian scatterer.

Fig. 2-3 shows that the 4D-LM fulfills the requirements of machine-tool and molding industry. Remarkable is the high sampling rate of the 4D-LM. One measurement lasts only 0.5 ms. A range image of e.g. 200x200 pixels takes only 20 s. As already mentioned each pixel contains not only the Cartesian coordinates derived from the slant range R and scan angles α_x and α_y but also the intensity the user gets real three dimensional image from the target's surface. The intensity information can be used to extract addtional information e.g. labels on the workpiece.

In the following chapters it will be shown by practical examples, how 4D-LM 's data can be processed so that the geometry of the object's surface is described. It will be shown that with the 4D-LM in combination with the new software module a very powerful tool exists which closes the gap for digitizing objects for later CNC-manufacturing.

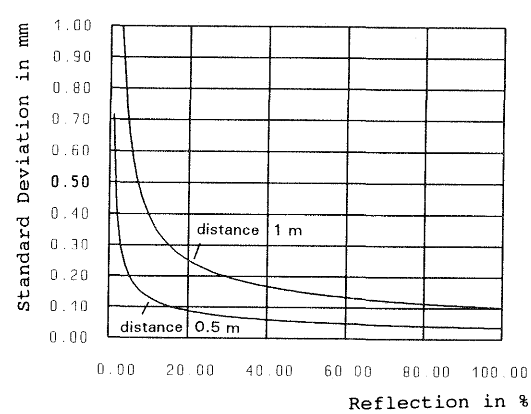

Fig. 2-4: Theoretical Accuracy of 4D-LM

3. INTERNAL COMPUTER MODEL GENERATION

After the digitizing of freeform surfaces by the 4D-LM measurement data are present in absolute Cartesian coordinates. They are transformed in object coordinates by a postprocessor. Now, the coordinates can be subsequently processed as either NC-commands for dublicating milling machines or in data format for the sculptured surface modeller.

3.1 Postprocessing of Objects Coordinates for Dublicating Milling Machines

Analyzing NC-programs of dublicating milling machines we found out that the coordinates of the cutter center point (x_{cp}, y_{cp}, z_{cp}) represent a set of loop contours. Normally the determination of loop contours is very time consuming. However, using the 4D-LM these special data sets can be determined very effectively by straight forward calculations.

As the object raw data are still distored by noise and therefore not useful for determination of smooth contours, they are filtered first by using best fit algorithms (Olomski, 1989) which can be interactively selected by the user. In a second processing step the loop contours are computed by defining virtual planes which are perpendicular to

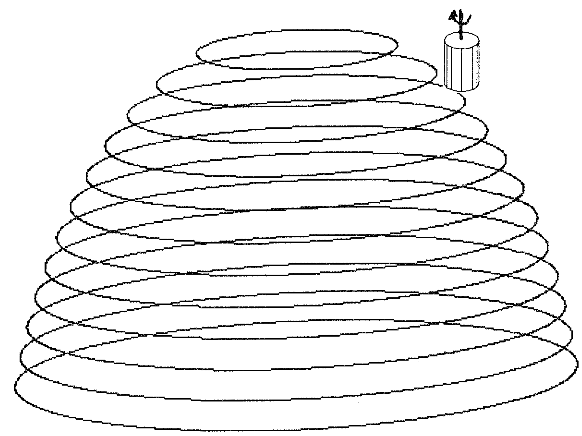

Fig. 3.1-1: Contours and Definition of the Cutter Axis

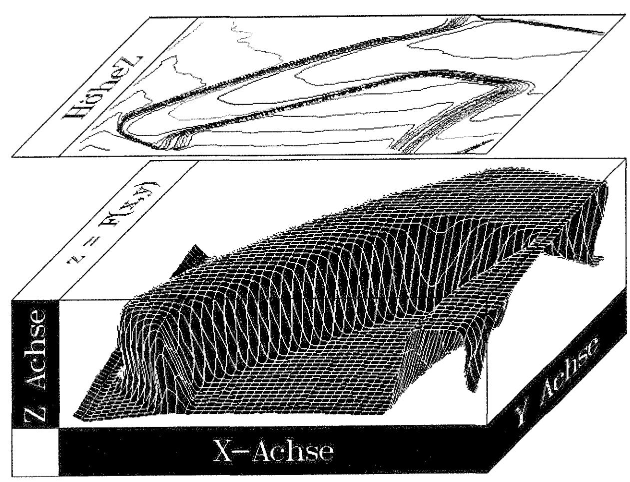

Fig. 3.1-2: Typical Workpiece Scanned by 4D-LM

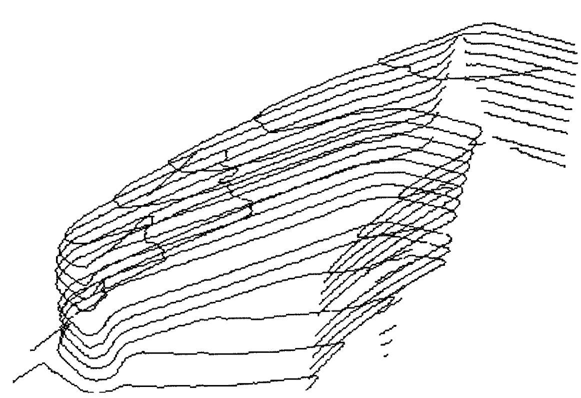

Fig. 3.1-3: Perspective View of the Workpiece's Contours

the actual cutter axis of the milling machine (s. fig. 3.1-1). The filtered raw data are rearranged and interpolated so that on every plane, loop contours are generated. These contours are described either by straight lines, by arcs or by splines. As these geometries are analytical formulated, they can be resolved in almost any required resolution. A typical example of loop contours built up by spline curves is shown in fig. 3.1-1. The workpiece was mapped by 4D-LM. The description of a surface by contours form the input for all further processing functions (e.g. positive, negative and pocket milling)and for the NC-program generation according to DIN 66025 or to a manufacturer specification format (e.g. FIDIA, Siemens, Bosch, Fanuc). In this processing level e.g. cutter orientation, cutter offset and material thickness are arbitrarily chosen by the operator. Within the NC-program generation all known geometric operations, e.g. rotation, scaling, mirror imaging and translation, are possible. In addition the user has the possibility of a visual control of the NC-program by simulating graphically the milling process on a display. The simulation result can be stored either in postscript file or an HPGL file for later printing.

Fig. 3.1-2 shows the measurement results of a typical workpiece in a wiregrid and the corresponding projected contours. In fig. 3.1-3 the contours are perspectively plotted. The contours are calculated from the three dimensional measurement data and are described by spline curves internal the computer model generator.

3.2 Surface Modelling and Data Generation for CAD/CAM-Systems

In current CAD/CAM- and CAP-systems which are applied in tooling and molding industry the molding workpieces are mainly modelled mathematically. In most practical applications the analytical description of such objects is not sufficient. In these cases an approximation and interpolation is necessary which rises the space and time complexity. If a freeform surface is digitized one has to handle a very hight amount of data (Mega Bytes) which demand too much calculation performance from existing CAD/CAM-systems. To solve this problem a data reduction is required to carry out an efficient data processing. E.g. by computing spline curves and spline surfaces employing different algorithms, a data reduction of better than 80% can be achieved in dependence of the complexity of the workpiece.

The following algorithms were studied and implemented:

- bicubic Bezier,
- polynomial representation (Coons),
- B-Spline,
- Non Uniform Rational B-Splines (NURBS) representation (s. fig. 3.2-1).

These computed internal representation of the digitized object is obtained by the Advanced Surface Modelling Software Package (ASMOS) developed by the Institute for Control Technology for Machine Tools and Manufacturing Systems (ISW) of the University of Stuttgart and can be processed by all 2D / 3D oriented CAD/CAM-Systems. For the Datatransfer within CAD's- and CAP's-Sytems following Interfaces are available:

- IGES 4.0 and
- VDAFS 2.0.

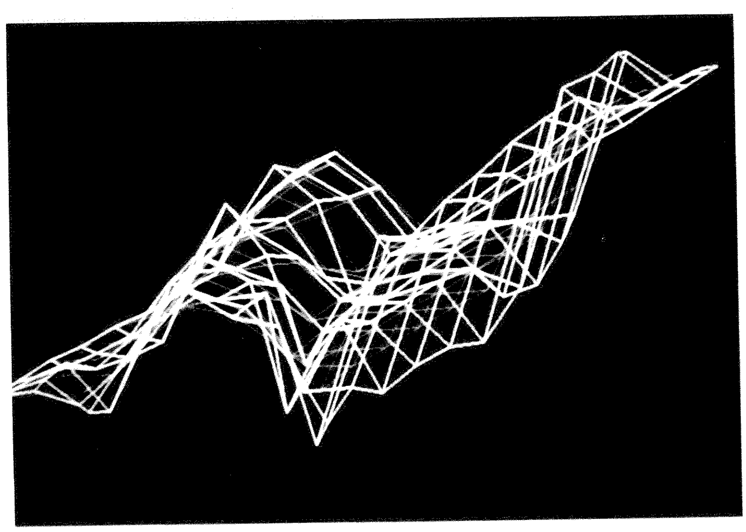

Fig. 3.2-1: NURBS Representation

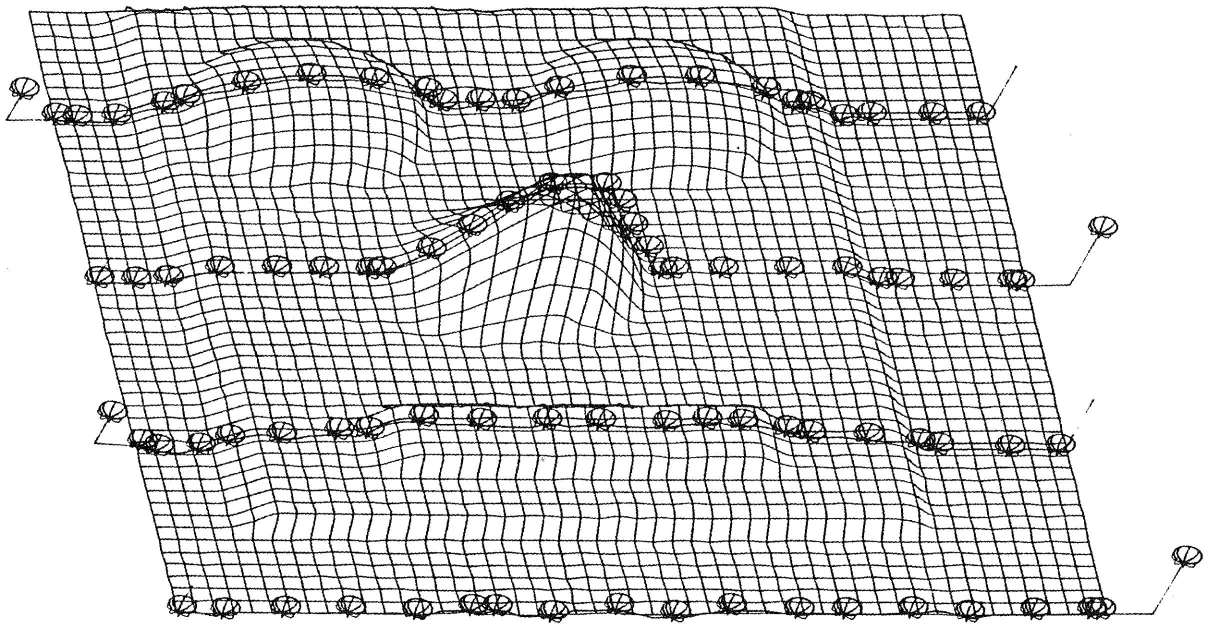

Fig. 3.2-2: 3D-NC-Simulation of a 100x100 Points Digitized Object

Employing ASMOS the resulting data of a scanned workpiece can directly be used on one hand for 3D-CNC-Simulation of the cutter path of a five axes milling machine (s. fig. 3.2-2) and on the other hand for direct milling the workpiece.

Using the 4D-LM and applying presented freeform surface modelling algorithms it is possible in the application field of CIM and especially of CAQ and CAM to close the manufacturing loop (s. fig. 3.2-3) very effiently. E.g. total cycle from mapping the master piece to generating freeform surface oriented CNC-data takes less than 2½ minutes for the test object shown in fig. 3.2-2.

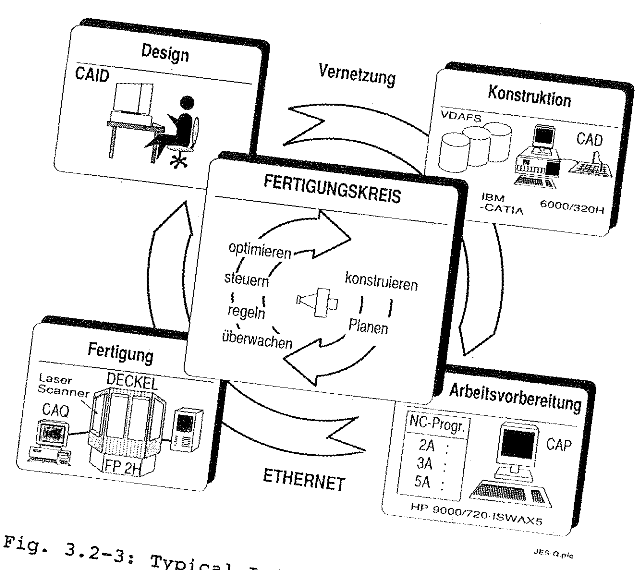

Fig. 3.2-3: Typical Industrial Production Loop

4. CONCLUSIONS

A new non-contacting optical four dimensional measurement system was presented. It could be shown that due to its high measurement accuracy in the submillimeter range the device can be used in the application area of manufacturing. However, to make optimum use of the 4D-LM a new sophisticated modelling software package was developed which regards the special scanning strategy of the mapper. Due to the computer internal representation of the scanned data it possible to shorten drastically the cycle time from prototyping to mass production. This is a key requirement of to-days manufacturing industry. The presented system realisation reduces production costs and improves the productivity and the quality.

In future development steps we will focus on volume oriented digitizing, modelling and processing. Then we will be able to carry out solid nominal-actual value comparison. In addition it will be studied if the measurement results could be improved by applying image processing and recognition techniques.

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