AN EXPLORATORY STUDY FOR A SOFTWARE INTEGRATED CONTROLLER OF A CMM

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Abstract: The CMM is a computer controlled robot for dimensional inspection, involving complex mathematical calculations and fast data transmissions both ways: computer (operator) – controller – actuators and reverse, probe – controller – computer . The delay between the operator command and the actual movement of the machine is significant, and other applications running on the computer increase this amount of time. Shortening the signal path by including the controllers in a software application will improve the transmission time and another features will be available. The portability of the programs developed in such application will be enhance, the readings will be more accurate and finally a new type of hybrid CMM could be developed. Our purpose is to trace the major lines of this project and develop an application to control the movement and to acquire data from a positioning system with steppers.

Keywords: Coordinate Measuring Machine (CMM), Touch-probe, Main Controller, Encoder, Optical ruler, Software integrated control

INTRODUCTION

Coordinate Measuring Machines dimensionally inspect manufactured parts to determine the geometrical errors and the shape deviations, in order to quality approve and certify the products of a company. Included in a schedule, length of an inspection is very important. Therefore in the last few years the main productive corporation of these instruments centered their research to improve the time consumed on the measuring process and also to acquire more accurate the data from the inspected shape. Even if the computer uses a fast Ethernet card and the transmission is as fast as it can be, the delay between the computer to the controller and from the controller to actuators is significant, particularly when other applications are running on the computer. A correct image of these components of a CMM is given in the next picture. The CMM ensemble is compound, in fact, of three controllers (the main controller, probe-head controller and touch-probe controller), the computer and the machine itself. Each controller has a precise task and the signals have a long path to cover. Also, we can add the processing time in every phase and the conversion of the signals in order to conclude the necessity for an exploration over a new technique and a new concept in building CMMs.

As it is shown in figure 1 the signal have to be process in several stages from its native start-up to the feed-back ending on the computer screen. The operator call a function and set up the parameters for a measurement in the program; the software is no more then a friendly interface between human and machine translating the operator intention in command signal. Then the signal is pass to the main controller where it is split between the actuators and the touch-probe controller. The motors put on move the arm; there are two speed phases: one for moving the probe near the inspected zone and one for touching the surface. Only when the machine is in measure stage (the prehit – safety distance from the surface inspected – is achieved) the signal from the main controller is passed to the touch-probe controller. After the deflection the probe is moved back to a prescribe distance (retract) and the arm rests. If the part geometry do not allowed to measure with the normal (A=0 , B=0) angle the operator might choose a different angle from a predefine list and the software pass another command to the probe-head controller. The feedback signals are gathered in the main controller, processed and converted in ASCI code for the computer. The reading signal is given by the touch-probe controller and the optical encoders read the position on the optical rulers and send the data to the main controller. All these consume time and the wiring is complicated.

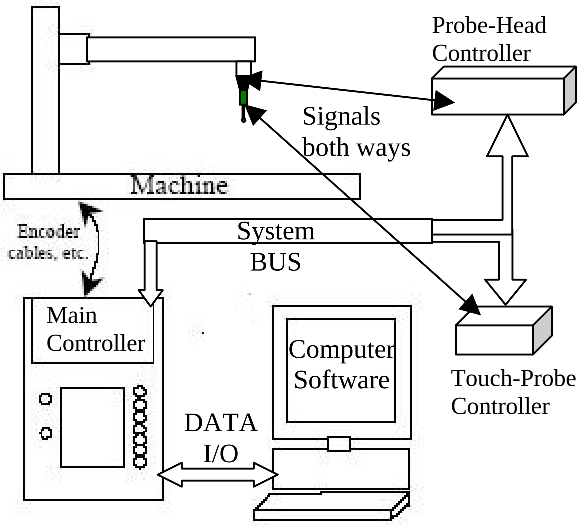

Fig. 1 - The CMM ensemble

1. SOFTWARE INTEGRATED CONTROL

Based on an article written by the J. B. Grimbleby from the Department of Engineering of the Reading University, "A Simple Algorithm for Closed-Loop Control of Stepping Motors " and combined with the growing necessity of time our paper explore a possible improvement of this problem. Our idea is to shorten the path of the information from the sensible elements of the machine; therefore we merge the software application with the controllers in a computer integrated solution, shortening, in this way, the time during the operator command , the actual movement of the CMM arm and back to the display of the results on the screen. This solution is sustained by several facts.

First of all, the machine uses either DC brushless servomotors or hybrid stepping motors moving to the prescribe position. If we considered the DC servomotors as actuators our solution is impossible to apply. A separated closed-loop controller is indispensable. There are two feedback loops in this kind of controller: the positioning loop and the current loop. The system topology and its adjustments are complicate and many logical circuits are involve. Also the space is wasted. But if the steppers are used, an software algorithm integrated in the main application can be apply to close the loop from the incremental encoders, and moreover on the same BUS the computer controls the touch-probe, the probe-head and read the data from the optical rulers. The electrical characteristics and the invariable load on the motor shaft claim the utilization of this type of actuators. From the electrical point of view, stepping motor is incremental mechanism and the input is a digital processed signal in order to obtain specific angular displacement. Each quantum of the input conduct to a certain portion of angular displacement, named step. A position is achieved after the rotor pass through all the intermediate transitions and the controller send out the entire drive sequence. The number of impulses prescribe the final location in the working volume of the CMM and the drive frequency is direct proportional with the moving velocity. The picture below show the close loop drive system, with a software algorithm instead of a classic controller.

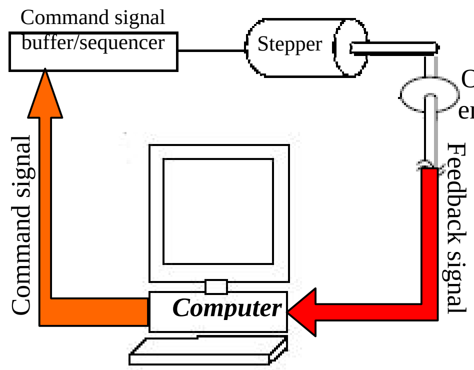

Fig. 2 - Close loop controller for one stepper (axis) integrated with the computer

The single external element beside the stepper and the optical encoder is a buffer before the motor to store the

input signal if the driving frequency is higher then the step rate. Another reason for this buffer is to limit overcharged currents from the electrical circuit and to protect the computer ports.

The coordinator controls the motion of several stepping motors generating, for each motor or axis, two signals: ***step*** and ***dir***. Conventionally the ***step*** signal is active-low and a 1-to-0 transition causes the motor to perform a single step in the direction determined by the value of ***dir***. For each axis there is a sequencer which accepts ***step*** and ***dir*** signals and converts them to the drive signals for the stator windings. A hybrid stepping motor has two stator windings, ***ph_1*** and ***ph_2***, each of which must be capable of being excited in either sense. In a 4-step sequence both windings are excited at all times and four steps advance the rotor by one tooth. Most hybrid stepping motors have 50 rotor teeth so that a 4-step sequence gives 200 steps per revolution and a step size of 1.8 degrees. A smaller step size is provided by the 8-step sequence in which eight steps advance the rotor by one tooth. This gives 400 steps per revolution and a step size of 0.9 degrees, but the improved resolution is obtained at the expense of a slightly reduced torque. By the other hand this decrease should not be a major problem thanks to the invariant nature of the load at the motor shaft and the impediment can be overcome using a more powerful stepper in order to compensate the lost torque. The algorithm is based on the digital signals ***step*** and ***dir*** . This two signal are a command position – ***cpos*** , a ideal prescribe position. The digital encoder outputs the real position of the motor – ***mpos*** (measured position). To achieve the prescribe position our controller should evaluate the error between ***cpos*** and ***mpos*** and pass to the motor's windings an excitation signal ***xpos***. In pseudo-code this algorithm can be translated as it follows:

```
if mpos - cpos < -2 then
      xpos := mpos + 2;
elsif mpos - cpos > 2 then
      xpos := mpos - 2;
else
      xpos := cpos;
endif;
```

Algorithm 1

To maintain a constant torque and to achieve the desired position the controller evaluates the error term ***mpos-cpos*** and as long as the error remains within ±2 steps the excitation signal ***xpos*** is independent of the motor position ***mpos***. This situation is acceptable for a positioning system that do not require a high performance, but the precision involved by technological processes demand a highly accurate positioning system.

Under closed-loop conditions the algorithm generates an excitation which is two steps in advance of the motor position and this provides maximum torque at low stepping rates. At high stepping rates, however, the current in the stator windings lags behind the excitation signals because of the effect of winding inductance. To obtain the maximum torque under these conditions the excitation should be more than two steps in advance of the motor position. To obtain a good overall performance it is therefore

```
if |mspeed| > sp then
      ea := 3;
else
      ea := 2;
endif;

if mpos - cpos < -ea then
      xpos := mpos + ea;
elsif mpos - cpos > ea then
      xpos := mpos - ea;
else
      xpos := cpos;
endif;
```

Algorithm 2

necessary to employ a variable excitation angle which changes from 2 steps to 3 steps as the motor reaches some predetermined rotor speed. The small increase in performance at very high rotor speeds which could be obtained by using an excitation angle of 4 steps does not justify the extra complexity. The control algorithm can easily be modified to incorporate a variable excitation angle ***ea*** under closed-loop conditions: where ***mspeed*** is the actual motor speed, and ***sp*** is the speed at which the excitation angle is required to increase.

This algorithm is a small part of a larger application and it refers only to the motor's controller. The entire positioning system has to evaluate another important signals came from the optical glasses of the each axes: ***px***, ***py***, ***pz*** .

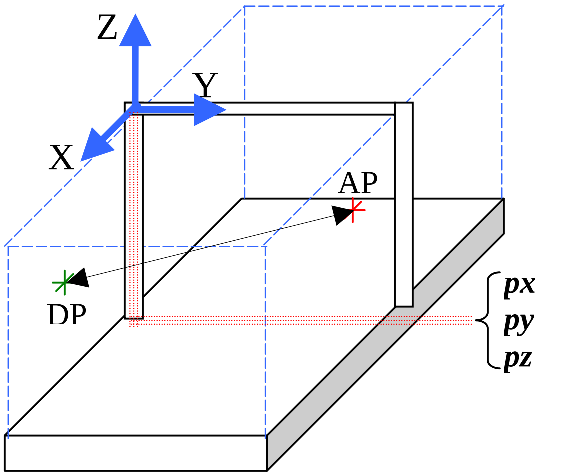

Fig. 3 CMM working volume

In Fig. 3. we draw the working volume of a CMM and the reference system recognized by the our controller. The optical glasses are read constantly and the movement is evaluated by the check-sum of the 100 mm check-lines. If the the sum is not in order an error signal is transmited to the coordinator and the system halt. For a simple ***AP-DP*** (***AP*** - actual position, ***DP*** –desire position) movement the coordinator calculate the distance and divide by 2 to obtain an intermediary position ***IP***. The distance from ***AP*** to ***IP*** is covered uniform accelerated and the second half the system decelerate so the final position ***DP*** will be achived with no error. This could be a proper control strategy for a prescribe movement, but other solutions can be discovered during the experiments. The decelerate phase have to be traveled as it is shown in the diagram (Fig. 4).

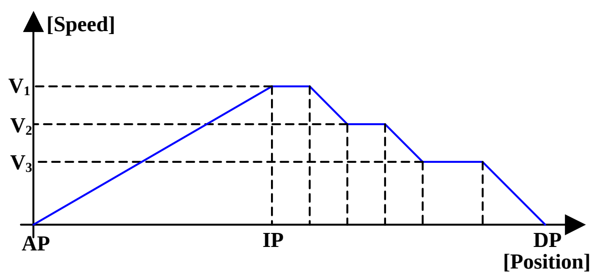

Fig. 4 Speed Diagram

The last steady speed ($\mathbf{v_3}$) is to be calculated from the data sheet of the motor in order to achieve the desire position (***DP***) with no inertia error or vibration. This type of system faults are a problem when the inspected zone is a pocket or a hole with a thin width and the prehit is smaller then the vibration amplitude, so the deflection occur unexpected conducting to false data. This is the reason why the last stage of speed have to be obtain accurate.

A timer and a counter are started for each axes to supervise the movement. The trajectory vector is decompose in its orthogonal components and the signals ***px***, ***py***, ***pz*** give the position of the mechanism in the working volume. The counter buffer store the distance traveled and the timer signal the switch of the speed stage. As long as the probe is within the first half of the entire distance the system is accelerated. When it reach IP position the speed is kept constant for a period determined by the controller. Then the speed is slow down step by step until the final position (DP).

This is the case of a simple movement between two discrete points of the working volume. The complexity comes when we try to control a movement on a curve or on a compound path for inspection of a mechanical part. Beside this, the increasing industrial needs require an intelligent automatic system that decide the most appropriate path to shorten the inspection time . The intelligent decisions and an adaptive control are the main attributes of a fuzzy controller. There are already researches in this domain, that bring in front the necessity of a fuzzy controller to drive such a plant. An article wrote by Grieco, Moroni, Nucci, Polini and Semerano speak about the solving of the CMM path planning problem using the fuzzy techniques. Their algorithm is based on the estimation of the proper touch probe path during the inspection. They assume that it is possible to define a set representing the fuzzy distance between the measuring point and the current position of the touch probe. If the distance is uncertain and expressed in term of possibility, the relative range may be represented with a fuzzy sets support range. Moreover represent the degree with which each value belongs to the fuzzy set possible distances. It is evident that, due to the complexity in the calculation of the actual inspection point distances, an heuristic algorithm, whose point distances are expressed in terms of possibility ranges, may obtain interesting solutions to the path planning problem. In the proposed algorithm the possibility ranges are approximate estimates of the actual point distances and fuzzy sets theory represents a useful and formal tool in the representation and solution of decision problems characterized by variables defined by means of ranges. To have a clue on the classic approach in this matter the Italian researchers give an example.

The complexity of exhaustive search is N!, where N is the number of measuring points in the graph, in the hypothesis of knowing a priori the optimal path connecting each couple of points. But, it is almost impossible to have this a priori knowledge. If we consider a mean of 50 measuring points, it means to compute 1225 paths: a fast algorithm, that takes 1 s for each path, will need approximately 20 minutes. This is not acceptable in a simultaneous design approach, where the solutions have to be on the fingertips of the designer.

A robust software application to drive a CMM including the two algorithms presented above could be a solution for many demands of the existing planning problem and the growing technology and gives the opportunity to develop an entire new race of CMMs .

2. MEASURE IN THE FUTURE

One major issue debated nowadays is the part programs portability developed under different platforms or software. There is a standard (DMIS) approved by all the CMM manufacturers, but has many inconveniences. The CMM programmers have problems to import an application made on a different CMM with other software. The new CMM is in fact a plug and play system and could be driven by any computer that runs the main application and the programmer can choose the type of the CMM that is work on through a part program procedure similar to the present declaration of the probe and the software after recognize it, begins the homing procedure. The programmer should also input the compensation matrix and than run his applications on the CMM.

For the new intelligent machines it can be design a new head-probe with higher resolution. For example, a latest technology CMM is equipped with a probe-head with 7.5° angular resolution. In the complex mechanical part measurement this resolution is not enough, but using a 1.8° stepper and a micro-stepping drive sequence this inconvenient could be overcome. Another feature for an accurate and fast inspection is to hybrid the touch-probe with a video-probe. The inspection process will look this way: the operator declare a part volume and defined it with input points. Then the machine automatically acquire images of the part and the software digitalize them in a CAD window according to the CMM reference system. Another window is open with the theoretical CAD data and the operator identifies the alignment for each fuzzy set the membership function will elements, the inspection zone and the fixture. The machine is now able to determine, according to an algorithm similar with the one developed by the Italian researchers, the proper drive path and send this movement commands to the actuators controlled by an intelligent program sequence that choose the best speed stages with no error and no vibrations.

This way the human error can be minimized to a insignificant level. The operator have the duty to fixture the part on the machine table, to input a few points and to supervises the measurement process in order to act in case of an unexpected failure.

CONCLUSION

If we have to discuss about the advantages and the disadvantages of the new controller – software integrated at least two improvements appear to the most significant. The first is related to the planning problem – everywhere in the world the time consumed by the industrial processes tend to be shorten. As an important industrial phase of the manufacture a product, the dimensional inspection are time consumer. There is a speed barrier for acquire a correct point or to achieve a position in the CMM working volume with no positioning error nor vibrations. That's why the inspection time could be decrease only from the electronically parts and the decision structure. But the fuzzy controller implementation and the designing of such a complex application could be a great impediment. The second asset of this new type of CMM would be the diminish of the human error. Almost every decision is made by the CMM fuzzy controller and important operations like alignments and path selection will be made automatically. But these procedure demand an advance and powerful process computer. An evaluation related to the price of this new approach have to be made in order to establish the economical implications.

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