Adaptive measuring enhancing the performance of a 5-axis laser robot machine

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ABSTRACT

In order to enhance the performance of our 5-axis laser robot machine to the full extent, we installed an adaptive measuring system with protection on the ending arm of the machine. This brings at least three virtues: a). Achieving measure functions by employing the same numerical-controlled mechanical structure without extra cost; b). Increasing the capacity, efficiency, and accuracy of the raw measured data into machining format (computer aided design (CAD) / computer aided machining (CAM) / computer aided processing (CAP) process); and c). Realizing 3-dimentional (3-D) intelligent measurement for large size workpiece (up to 3×2×1 cubic meters) with given measurement accuracy (to 12 μm). Discrete 3-D signal point data are acquired and processed automatically by a personal computer, and the program employing network predicting concept has adaptive function with which the single- or multi-step measuring is determined by the surrounding points. By means of intelligent measurement a fast and effective measurement can be carried out for even a complex surface.

Key words: adaptive measurement, laser machine

1. INTRODUCTION

Measurement is a very important job in modern industry, in particular, with the appearing of rapid prototyping (RP) it becomes even crucial. Generally speaking, jobs of measurement and machining are separated conventionally. The former is performed on a coordinates measure machine (CMM), and later is done on a special kind of machinery. This way is still common in current industrial manufacturing processes.

It is obvious that integrating functions of measure and machine on one set of equipment is necessary and valuable. By doing so, one can not only cut the equipment cost, but also make the equipment more powerful. We have designed and installed a 5-axis laser robot machine[1] with which one can carry out many types of laser materials processing, such as drilling, cutting, welding, surface modification, and RP, etc. In addition, an object measurement can be also performed with this equipment. When the 4th-axis and the 5th-axis are fixed to avoid rotating and swing, it is at least equal to a CMM functional, but with different measure principles. If the 4th-axis and the 5th-axis is used for rotating and swing, one can realize an omnidirectional measurement on a complicated object. Thus, this robot system can be used for measurement apart from laser machining, and provides necessary data for later processing. We also study on the concept of adaptive measurement of a workpiece surface, which may improve measure efficiency in great deal. Because of having an additional function of measurement, the 5-axis frame-structured laser robot equipment has more performances.

2. STRUCTURE OF 5-AXIS LASER ROBOT MACHINE

In many cases, the operational computer aided manufacturing (CAM) data are obtained from the acquisition of measurement of an actual workpiece.[2,3] Our 5-axis laser processing system is designed in such a way that both measure and machine operations may be performed with one set of equipment (same structure and control system). The probe or laser head can be installed at the end of revolving /swing arm of the 5-axis frame robot, as shown in Figure 1. When the probe installed, it can acquire the row data with relatively high accuracy (ca. 5~100 μm in 1×2×3 m^3 effective section) showing some advantages over the joined arms robot. It also has low manufacturing cost compared with the gantry type equipment. Apart from the mechanical structure, the system consists of a numerical controlled industrial laser system (with a VC++ platform in both English and Chinese), which emits an output of 500 W average (it can be expanded to 2000 w), or 50 J per single pulse (it can be expanded to 200 J), a 20m long optical fiber delivery system, and an optical machining head with laser beam shaping element unit for various application requirement.[4,5]

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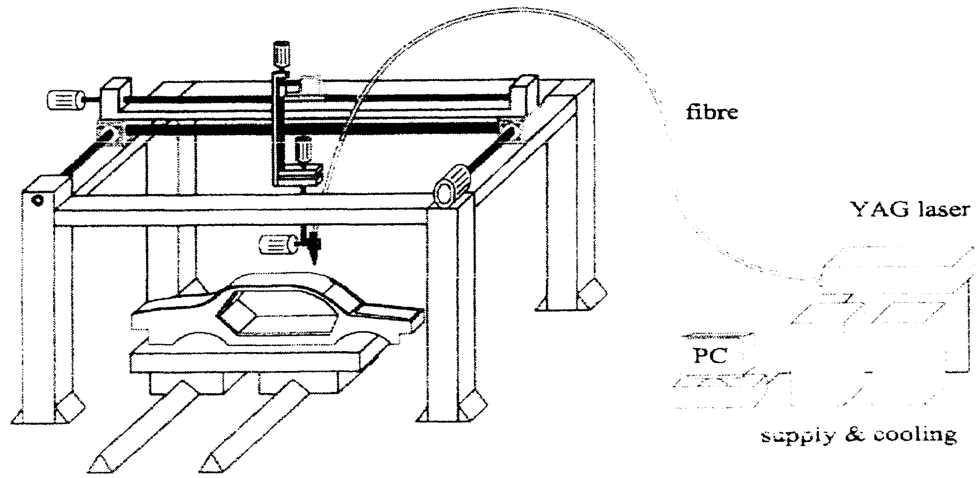

Figure 1. Schematic diagram of frame structured 5-axis laser robot system

Figure 2 illustrates a block diagram of a logic operational principle of the 5-axis robot system, where measure and machine performances share one executive unit, i.e. the multi-axis (*X, Y, Z, A*, and *C* coordinate) robot executive control unit. It embodies achievement of the concept of computer aided integration of measure and machine process, even design and plan. Once the measuring process is completed, the data will be treated and formed into the one for laser machining. A special designed and made clamping apparatus is mounted to the end of revolving/swing (*A*, and *C* axis) arm for easy replacement of probe and laser machine head with relatively low installation error. The *X, Y,* and *Z* axis in mutual vertical position supplies a fast and accuracy movement, but *A*, and *C* axis supplies the posturing of the laser machine head. Therefore, one can carry out 3D measurement and multiple materials processing with this frame robot 5-axis laser machine.

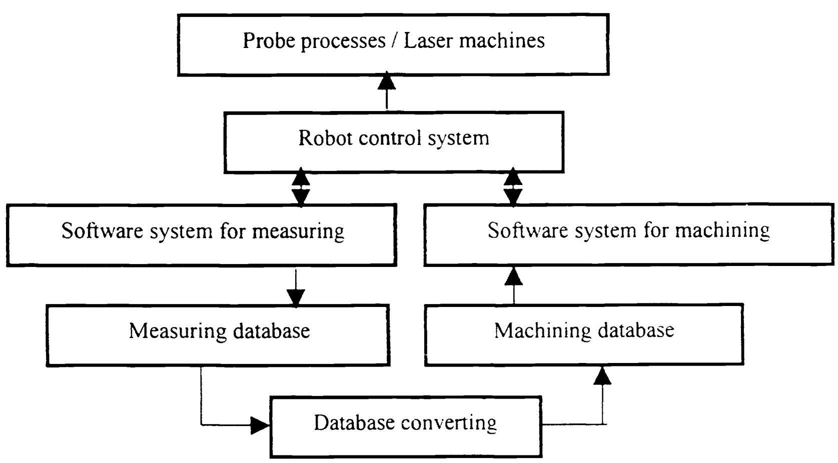

Figure 2. Block diagram of the principle for measure and machine

3. MEASUREMENT PRINCIPLE OF 5-AXIS LASER ROBOT MACHINE

The 5-axis laser robot machine can used to perform measurement as a CMM, but its measure principle differs from that of CMM. Although CMM can be used to realize an omnidirectional measure, it depends on the self rotating and swinging of the probe. For the upstream computer, such actions are negative, as the upper computer does not have a control function of CMM. For our 5-axis laser robot machine, the omnidirectional measure is realized by rotating the 4th-axis and swinging the

5th-axis. It is absolutely positive to the upper computer, as a completely control function has been obtained for the position and posture of the probe, mainly contributed by the outstanding structure design of the 5-axis frame robot system.

The Measure principle of a 5-axis robot is discussed below. A contact probe is adopted by the 5-axis robot to perform measuring. Such probe is equal to the performance of an electronic switch. When touching the workpiece surface, it brings out a trigger signal. Once the signal coming, the robot records the current coordinates and stops moving of the probe. Then one cycle of measure is finished.[6] During this process, the time-related conditions of robot axis, probe signal and robot controller are shown in Figure 3.

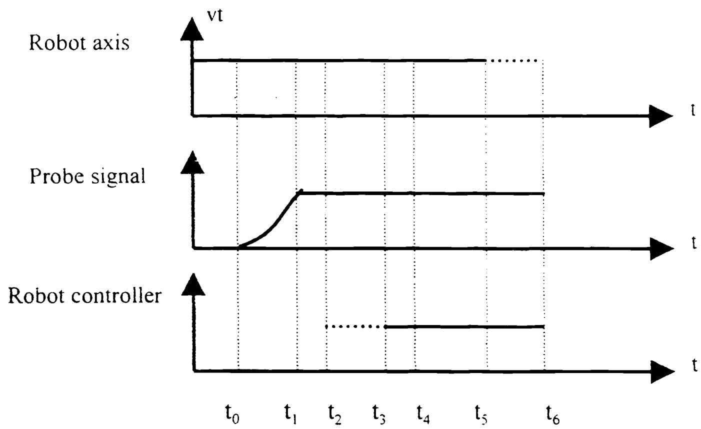

Figure 3. Time order conditions of robot axis, probe signal and robot controller within one measure cycle

At time t_0, the probe touches the workpiece and a trigger signal is generated. The signal reaches the threshold value at time t_1 and a pulse is formed. At t_2, the pulse signal comes to the robot controller which gets the signal at t_3. Immediately the controller sends an instruction to stop moving of the probe. At t_5, the probe stops. Then the controller reads the coordinates in terms of floating digits, which are the current measuring values.

During this process, such time intervals as from t_1 to t_2, and from t_3 to t_4 are very short compared with other time intervals and hence they can be neglected. The other three time intervals will influence the measure precision. Firstly, from t_0 to t_1. This is the probe trigger timing, which produces pre-travel error. Secondly, from t_2 to t_3. This is robot scanning timing. Because of the self-characteristics, the robot can always capture the signal within one code period. Thirdly, from t_4 to t_5. It can be called the system dynamic response timing. The robot can also come to a stop within one code period. As for a TP2 type of Renishow made probe adopted, its pre-travelling error is ca. 2μm. Figure 4 demonstrates a response curve with measuring speed of 10mm/s of the probe. The Line displacement of one code is 5μm. Therefore, the total error of probe system is approximately 12μm, which is satisfied for most of general measuring in our cases.

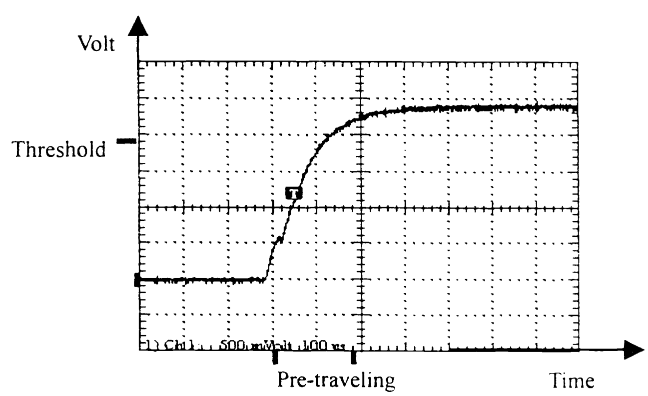

Figure 4. Probe's response curve with measuring speed 10mm/s

Differing from CMM, a static reading is adopted when measuring by this robot system. That's to read coordinates when the robot has already stopped. Of course, dynamic reading can be also used. In this case, coordinates are read immediately once the trigger signal reached the controller of the robot, regardless of the robot stopping. Both measuring errors are in the same range. However the later is a little more difficult to realize.

4. STRATEGY OF ADAPTIVE MEASUREMENT

One of the aims that the robot has the function of measuring is to provide data for laser machining. Surface geometry model of a workpiece can be produced from measuring data, then geometry parameters of the surface used by laser machining can be obtained. The measure points for data acquisition are intelligently distributed on the workpiece surface in such a way that they depend upon the feature of the surface. This is so called adaptive measuring. According to the difference of optimum target when measuring, there are two methods to perform adaptive measuring.

4.1. Surface shape oriented adaptive measuring

Such a method of adaptive measuring is aimed at identifying surface shape. The process is illustrated as below. First the surface is fitted based on historical measure data, then by the appropinquity between fitted surface and actual surface, to determine the position and amounts of later measure data. These tasks are all finished in one measure cycle. Seen from robot control, the flow chart of robot finishing adaptive measuring is like Figure 5.

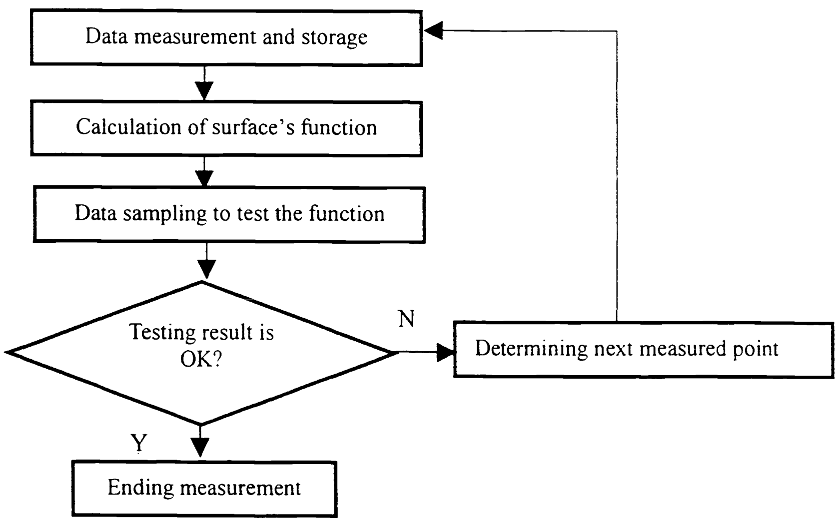

Figure 5. Flow chart of robot adaptive measuring

Figure 6 shows an example of 2-D adaptive measuring.[7] The historical data are points 0, 1 and 5, 6 based on which to predict the trend of the curve, the moving height of next measuring data is calculated. This value of height changes with the feature of the curve. Thus adaptive measuring is realized. It is easy to extend to 3-D measuring from 2-D measuring.

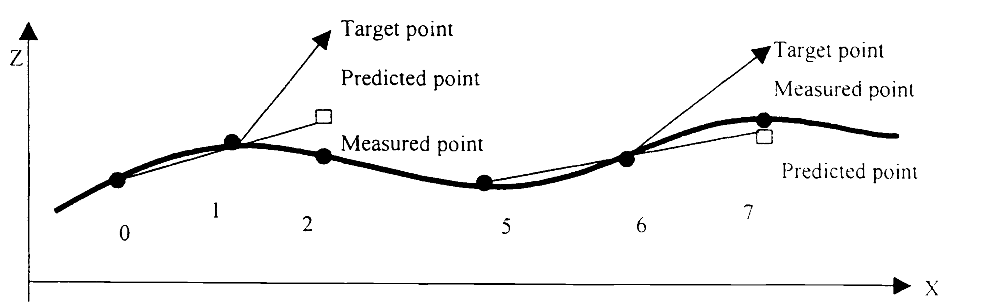

Figure 6. Example of 2-D adaptive measuring

4.2. Machining process oriented adaptive measuring

Using above method, we can get discrete measure data. These data are fitted to form surfaces, then geometry parameters can be produced. It is actually a CAD/CAM process. For laser machining, measuring job is mainly used to serve machining. If measuring process can be driven directly by machining parameters, we can not only get machining data when measuring, but also combine measuring and machining more compactly. This is the basic idea of machining process oriented adaptive measuring.

In fact, a serial of function transform is executed when using the first method of adaptive measuring, the focus is to get the fitted surface. Since most workpiece can not be represented by one surface function, the surface finally gained is always be combined by many applets. In most cases, the surface function does not exist. So surface fitting is approximate. Since it is a function mapping process from measure data to machine data, naturally we think of neural networks, which has high ability of non-linearity mapping. It can be used to realize this process

For neural networks used in the process from measuring to machining, its inputs are the condition parameters of next measuring data, and outputs are machining parameters. Realization of this process should be studied comprehensively.

It should be pointed out that besides measuring data is adaptive, the posture of probe is also adaptive. Generally, the probe tip direction deviation should not exceed $\pm 45^0$ of the normal line. This not only avoids probe gliding on the workpiece, but also makes the precise probe compensation easy in real time. For a given workpiece surface, the measurement will begin to vary along the direction of probe approach to it deviates further from that angular range. The 5-axis laser robot can easily realize this adaptive requirement.

5. DATA CONVERTING FORM MEASURE TO MACHINE

Measure data form one discrete database. Since these data are always not machine data, and the tool, the position and the posture of robot are different during measuring and machining, this database can not be used to machine. Measure data must be transformed then it can be used in machining, such process is shown in Figure2.

The simplest case is that measure data are machine data, and the robot's posture when machining is same as it when measuring. Measure data can be transformed easily to machine data by compensating length difference of tools (the laser head and the probe).

$$Z_{\text{machine}}=Z_{\text{measure}}+(L_{\text{laser}}-L_{\text{probe}})$$

Where, Z_{machine}—machine data
Z_{measure}—measure data
L_{laser}—length of laser head
L_{probe}—length of probe

The most common case is that the measure data are not machine data. In addition, because of the particularity of laser machining, normal to the machined curved surface is required, which becomes the reference direction when machining. If not using surface shape-oriented machine process, much software can be used from measure data to machine data. Things will be simpler when directly using measure data to produce machine data. For instance, giving three measure data in the space, (X_1, Y_1, Z_1), (X_2, Y_2, Z_2), (X_3, Y_3, Z_3), the normal to the plane formed by the three points is easily gained. Two lines through the three points are L_1 and L_2. Their direction vectors are:

$$L_1=(X_2-X_1)\ i + (Y_2-Y_1)\ j + (Z_2-Z_1)\ k$$
$$L_2=(X_3-X_2)\ i + (Y_3-Y_2)\ j + (Z_3-Z_2)\ k$$

Then the normal set to the plane is the multiplication cross by L_1 and L_2, $L_1 \times L_2$. Finally, the machining direction is easily produced by its outcome.

6. CONCLUSION

The structure designing of 5-axis laser robot is mainly to satisfy many types of laser machine, it is especially suitable for machining on a large scale and random surface shape. This structure provides the function of measuring, and because of the 4-axis rotating and the 5-axis swinging, omnidirectional measuring can be realized. This is the result of the combination of robot and probe working together. The measuring error is determined by the robot frame-structure, the robot control system and the probe system. Some results have shown that the measure can be satisfied in general requirements.[8] Because of having measuring function, the robot can be operated to digitize workpiece surface. Through the CAD/CAM processing, laser machining can go on. Thus, with a set of the equipment one can realize the measure, the control and the machine integrated. With this robot one can also perform routine dimension verification. By doing these we not only decrease the cost of the 5-axis laser robot machine, but also enhance its performance.

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