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PERFORMANCE ANALYSIS OF COMPUTER CONTROLLED ASSEMBLY SYSTEMS

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Abstract A human operator assembles components using his skill and judgement which is difficult to incorporate in a mechanized device. Though the mechanized system will offer higher speed and reliability, but its inherent inaccuracies will limit the success in assembling. Thus, it is essential that these inaccuracies are determined to establish its 'Process capability' , and also provide information for design modifications to be done on the components to be assembled to improve the success rate of assembling on these mechanized devices.

Keywords : Assembly, Mechanized, Program controlled, Process capability.

1. INTRODUCTION

Mechanized assembly devices cannot match the dexterity of the human operator since these have very limited decision taking capabilities and are also constrained by inherent errors in their mechanisms and limitations of their controllers. Therefore, to assess the success in assembly operations by these devices, it is necessary to establish their 'Process capability' and thus the working tolerances on components to be assembled can be estimated. To take into account the system inaccuracy, the components to be assembled need to be modified. These modifications should be such that the functional aspect is not affected. However, if it does due to these increased tolerances, it would then make it imperative to make improvements in the accuracy of the system. Thus it can be said that accuracy requirements to obtain final assembly is important in relation to the performance of the system.

Assembly operations, in present day industrial scenario, are needed for small and medium batch manufacture. This may call for repetitive work for short durations. Automation of assembly work of this nature can be possible by program controlled devices such as CNC used for machines tools[Heginbotham, 1970 & Oswald and Munoz, 1998]. The nature would not be identical since in assembly work, precise positioning and high speeds of movement would be essential aspects. The machine should be capable of handling families of similar assemblies by a program control whereby components can be selected in any desired order and placed at any desired location, i.e. high versatility alongwith high demand rate. It would be appreciated that in such a system the changeover from one batch to another would involve lesser down time[Heginbotham & Tewari, 1975].

2. ELEMENTS OF ASSEMBLY SYSTEM

There can be various designs of an assembly system [Boothroyd, 1968] but the most common and simple one is the Cartesian type. Here, the assembly table can move along X axis while the arm, carrying the gripper, move along Y axis. The gripper assembly can move in Z axis to pick or place the components after the assembly system has reached the required position of pick or place in the XY plane. The arrangement is shown in Fig.1.

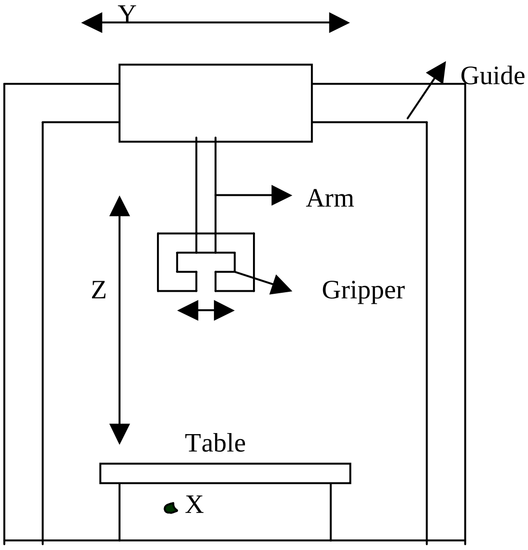

Fig.1 Cartesian type assembly system

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3. CLASSIFICATION OF ERRORS

On study of the assembly operation, the errors which affect the success of the assembly are observed and are as follows[Heginbotham and Tewari, 1975]:

(a) Mechanism errors along X and Y axes
(i) in alignment
(ii) in positioning
(b) errors in gripper arm
(i) in holding of components
(ii) in its motion perpendicular to XY plane
(c) errors in components, their orientation and their placement in fixtures.

From the point of view of brevity, only errors classified under (a) have been discussed in detail here. In initial trials, it was found that magnitude of errors of type (b) and (c) was of low significance than type (a).

The summation of the errors is then carried out along X and Y axes and then the clearance required between mating components is calculated as $E = (Ex^2 + Ey^2)^{½}$. This, in other words, is termed as 'process capability' of the assembly system.

3.1 Errors in the Elements

An ideal cartesian assembly system would be in which the table and the arm move in exact straight lines, perpendicular to each other. Also the gripper assembly would move in straight line, exactly perpendicular to the plane containing the lines of motion of the table and the arm. However, such an ideal system is economically and even otherwise, not possible. Therefore, it is imperative, that the system errors be determined to ascertain its capability [Heginbotham and Tewari, 1975, 1978]. To start with, motion of the table, along X axis, can be experimentally checked by conventional method of autocollimator and reflector block (Fig.2.). The reflector is clamped on the table and the autocollimator is placed at a distance away from the table, in line of sight. The table is programmed to move, to and fro, randomly covering the entire extent of its travel, and the readings of the collimator are taken, at each halt, for the shift in Y direction. A plot of the same can be obtained and the best fit can be determined indicating the actual motion of the table, i.e. deviation from the true straight line.

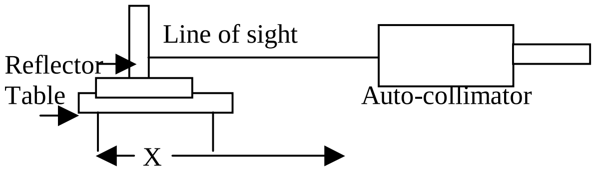

Fig. 2 Checking X travel

Similar experiment can be performed for travel of the arm on the guide, i.e. Y direction. In this case, the reflector is held in the gripper and the autocollimator is placed along the line of sight in Y axis direction. The arm is programmed to move and readings taken for the shift in X direction , similar to as in earlier experiment for the table motion. The equation for the motion for the two elements can then be empirically stated as:

For table : $y_s = a_1 + b_1x + c_1x^2 + d_1x^3 + \ldots\ldots\ldots\ldots\ldots....$

For arm : $x_s = a_2 + b_2x + c_2x^2 + d_2x^3 + \ldots\ldots\ldots\ldots\ldots\ldots$

From these two equations, it can be predicted that if any position (x, y) has been programmed for placing the component, then the position achieved will be $(x \pm x_s, y \pm x_s)$ which incorporates the errors, due to non straightness in travel of the arm and the table. A number of sample runs are made and then the spread of these errors (t_{sx}, t_{sy}) is estimated, thereby for any position programmed , the position achieved can be determined.

3.2 Errors in Programmed Positions

The motion of the table and the arm can be obtained either by lead screws or pneumatic/hydraulic linear drives. The position attained, along the direction of motion of the element, can be different from the programmed position, because of the inaccuracy in the screw/piston-cylinder system, e.g. pitch, backlash, leakage etc. This error can be determined by installing a linear transducer (say, Morie' Fringe type)along the direction of motion of the element being examined. The element should be programmed to reach a large number of positions, chosen randomly, and a record be obtained (with help of a microprocessor based device) of the transducer readings for every programmed position. The randomness will enable taking into effect errors due to bi-directional motion. The number of readings to be taken should be statistically found for a particular degree of confidence, generally 95%. With these experiments, the inaccuracy in reaching any particular location in XY plane can be determined as:

(i) In Y direction : as summation of error in straight-ness in motion of the element X and error in positioning of the other element (Y), and correspondingly.

(ii) In X direction: as summation of error in straightness in motion of element Y and error in positioning of the other element X.

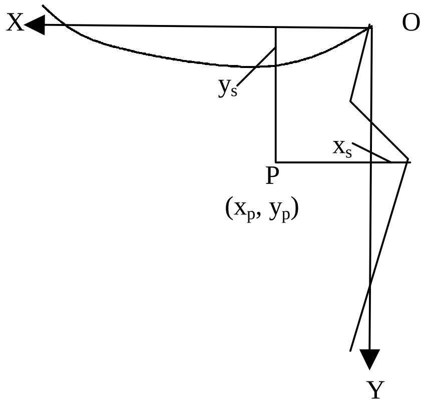

Fig.3 Inaccuracy in assembly system

Fig. 3 illustrates the inaccuracy involved. If the assembly system has been programmed for the position P, then due to errors in straightness, the location reached will be ($x_p - x_s$, $y_p + y_s$). Based on the trial runs, the repeatability of positioning is estimated. The mean (p) and standard deviation (sd) are determined. Then if any position (x,y) is programmed, in the worst case the error in position attained will be $\pm t_{px}$, $\pm t_{py}$ where t = 3.sd. The systematic errors p_x and p_y will be accounted for in initial setting of the system. Thus overall error in reaching a given coordinate will be

Systematic error in X direction = x_s

Random error in X direction = $\pm (t_{sx}^2 + t_{px}^2)^{1/2} = x_r$

Similarly, errors in Y direction can be calculated. Thus, required clearance between components to be assembled by the system will be:

$$2 [\{x_s + x_r \}^2 + \{y_s + y_r \}^2]^{1/2}$$

This is also termed as the ‘ process capability’ of the assembly system.

4. VERIFICATION OF PROCESS CAPABILITY

A large plate (of area equal to assembly area available on the machine) with very precise holes at random positions can be used for verification test [Heginbotham and Tewari,1978]. A hole in the left hand bottom end is taken as reference by programming a pin to position (0, 0) at this location. The plate is adjusted and clamped on the table in this position after alignment in X and Y axes. Based on the process capability data, low toleranced pins are chosen whose dimension would enable assembly in the holes. That is to say, that pin diameter = Hole diameter – E, where E is as defined in section 3 earlier and determined experimentally later in section 3.2. Now the machine is programmed to carryout assembly operation at various holes. More than 4000 assembly operations were performed. For 95% success in the assembly operation, i.e. 0.05 fraction defective (failure in assembly), expected failures would be 225 (for 4500 attempts). In actual operation, this was found to be 166, i.e. 0.037 fraction defective.

Though the process capability is thus verified but it would be seen that the actual performance is better than theoretically predicted. This is attributed to

(a) compliance in the system, i.e. slight chamfer present on the hole and pin ends, which facilitates entry. This is also termed as lead-in.

(a) vibration in the system in XY plane, due to high speeds of operation, which might also be helpful in entry.

CONCLUSION

This work indicates that performance in quantitative terms, i.e. Process capability of a computer controlled assembly system can be determined by summation of its errors. This information can be found useful in designing the machine to suit specific clearance requirements between components to be assembled; or, for assigning tolerances on components which could be assembled on the system. In case the assembly requirements are precise, the information could be used to determine the compliance, in form of lead-in, to be provided on close fitting components.

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