# SIMPLE ARCHTECTURE FOR A MANUAL AND SERVO ASSISTED, HYBRID SYSTEM FOR POSITION CONTROL IN MACHINE TOOLS

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***Abstract.*** *The objective of this work is the proposal of a new strategy for controlling the position of a cutting tool relative to a machined part. This works starts with the comparison between manual machine tools and the numerically controefled (NC) machine tools. Despite the high eficciency in terms of accuracy and speed, NC machine requires a considerable time to preparing it, i.e., it requires time for generating the cutting path and then, programming the machine, by using specif programming codes. Besides, the prepared program must be debuged. On the other hand, manual conventional machine tool, although having an elevate flexibility – it does not require programming, has low efficiency, compared with NC machines, since fine positionings must be executed manually, by moving handles carefully. The final goal of this work is the development of a machine tool that has a characteristic intermediate between a NC machine and a manual machine tool, i.e., a machine in which, the motion of the cutting tool is defined by the human operator and a servo system helps the operator to reach the desired positioning faster. For this goal, this work presents a positioning strategy composed of: a) a manually driven sliding table, b) a position sensor that monitores the table position, c) a magnetic brake that locks the handle when the table reaches the desired position and d) a computer that executes the control algorith. The control strategy is presented considering a motion in only one direction. A prototype is developed and constructed. By positioning tests, the effectiveness of the strategy is demonstrated. The system enables a fast and precise positioning of the table, with the operator driving the table through handles. Comparison with completely manual positioning shows that by the proposed strategy, a faster positioning is possible.*

***Keywords*** *position control, precise positioning, servo-assisted positioning, hybrid control, machine tool control*

## 1. INTRODUCTION

Figure 1 presents a widely known graph that expresses the relationship between the lot size and the production cost, considering three types of production machines: the manual machine, the numerical control (NC) machine and the transfer machine (see for example Groover, 2000). For lot sizes over than 100 pieces, the transfer machine, used to compose a transfer line, is the most interesting machine for the production. Although its initial cost, as well as, the set up cost is high, its productivity is the highest among three types of machines. Therefore, the use of transfer machines is more interesting as larger the lot size. For intermediate size lots, from 10 to 100 pieces, the NC machine is the most suitable since it presents a cost and productivity intermediate between a manual machine and a transfer machine.

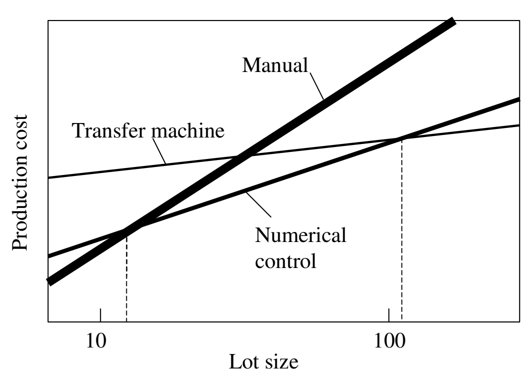


Figure 1. Machine type according to the lot size and the production cost

Finally, for small lots, up to 10 pieces, the manual machine becomes interesting since, besides its cost is the lowest between three type of machines, it does not require a high cost specialist, the programmer, the programming activity (see for example, Chang *et al*, 1997) and all works necessary to prepare a NC machine. It is important to observe that the human operator is that offers major versatility for, in a short time, promote adaptations for a new job, that is, flexibility.

Each value presented in Fig.1, that determines the transition from one type of machine to another is merely examples, only to suggest that such limits exist. These limits vary according to the technological evolution and the development of new type of machines. Thus, for example, a new NC machine with higher productivity, will make the transition for transfer machines changes to a value higher than 100. By the other hand, a new NC machine with a more simple programming and set up, will make the transition for manual machines reduce do values smaller than 10. This graph also illustrates one of the reasons why the NC machines are widely used in the manufacturing. In recent yeas, the market changed its behavior, requiring new products at shorter time intervals. Therefore, the lot size has been reduced and the variety of products, increased. In this scenery, the NC machine matched well to the new market profile.

Above mentioned trends persists until now and the lot size is decreasing constantly. Among other things, this leads to the necessity of a machine having characteristics intermediate between a manual machine and a NC machine (Fig. 2). This is the goal of this work. In one hand, it is desirable a NC machine with more simple programming. At the same time, it is desirable, a manual machine with a higher productivity. It is also relevant to mention that such machine is of great merit from social aspect since it will revitalize the human work force, offering a solution for problems of lack of jobs as consequence of high level of automation in the modern factories.

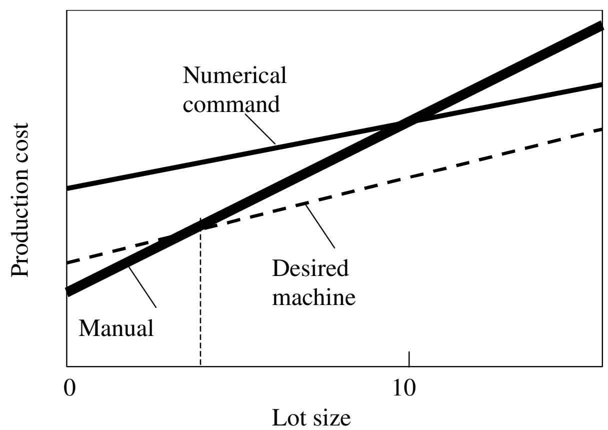


Figure 2. Machine, desired in this study

Contrasting to the proposition of this work, some answers are already presented for the trend for small-lot large variety production, as mentioned above. These are the concepts of FMC (Flexible Manufacturing Cell) and FMS (Flexible Manufacturing System), subjects described, for example in Zhou (1999). Both are based on NC machines, robot manipulators, material handling devices and a sort of highly automated devices that are integrated and controlled by computer. Due to their high level of automation and integration, the FMS and the FMC are capable of quickly adapting to the production of a different product (see for example Groover, 2000). Also the concept of Agile Manufacturing was developed (Gunasekaran, 1998), however this approach is based on the use of machines with high level of automation. In opposition to this trend toward total automation, the idea of Balanced Automation was developed (Camarinha *et al.*, 1995, Riascos, 2001), stating an adequate equilibrium between the automation and the use of the human labor. The proposition of this work is in consonance with the Balanced Automation.

Concerning the difficulties related to the programming of a NC machine, there are several works concerning strategies for automatically generate the tool path and, consequently the NC part program from the drawing of the product. See for example, Ruan *et al*. (2005) and Ching-Fong *et al*. (1995). However, proposed strategies implies in an intensive computational work and, moreover, no universal computing strategy capable of trating any type of machining and geometry was developed. Human operator is capable of deciding the tool and the machine to be used, creating a tool path, simply looking the drawing and the rough material. The operator is not able to optimize the tool path as efficiently as the computer, however, the optimization is not so relevant in the production of very small lots, as is focused in this work.

## 2. ANALYSIS OF A MANUAL MACHINING AND PROPOSITION OF NEW STRATEGY

A simple analysis of the operation of a manual machine suggests the reason why the manual operation demands much more time than an operation in a NC machine. Moreover, it is possible to identify, which step of a manual operation is the most time consuming.

Figure 3 illustrates the three steps in a manual machining. The machining consists basically on repeating positioning of a cutting tool into a desired position by turning a handle. Knowing the position toward the tool must be conducted, the operator: (a) in a first step, turns the handle, verifying the moved amount by means of the scale in the handle, trying to keep the optimal speed for cutting, (b) in a second step, when the tool reaches at a position near the desired position, the operator moves the handle slowly so as to not transpose the desired position and (c) finally, the operator proceeds to a careful positioning, manually controlling the position, until fractions of division in the handle scale.

A minimal experience in machining clearly shows that, quantitatively, the moving speed changes significantly along the mentioned steps, as illustrated in Fig. 4. The speed drops in steps (b) and (c).

It is intuitive that, as higher the desired machining accuracy, the larger is the time required in the step (c). Also, as much the amount of details to be machined, as much will be the time demanded in steps (b) and (c) and as less will be the relative length of steps of type (a). Therefore a considerable reduction in the machining time, i.e., an increase in the machining efficiency, can be achieved by increasing the efficiency of the machining in the steps (b) and (c), that represent the steps related with the precision positioning.

This leads to a solution for the machine mentioned in Fig. 2. The machine should have following features.

(i) Its motion should be based on manual operation, eliminating the necessity of programming. The human operator decides on site, the trajectory described by the cutting tool giving to the machine a highest level of flexibility.

(ii) It should be equipped with a device that will give support to the human operator only when doing precise positioning enabling a more efficient machining.

To realize item (ii), this work proposes the use of the concept of "prohibited region", a region (surface or volume) into which, the cutting tool cannot enter. The machine to be developed, should be equipped with a servo-system that: (1) monitors constantly the position of the cutting tool, (2) stores the contour of the work piece to be machined, (2) enables operator to move freely the tool in the space outside the prohibited region, (2) lock the motion when the tool touch the prohibited region.

Even though, there are many possible ways of realizing the above mentioned control. In another work, authors proposes a machine that, having a NC machine as base, the tool is moved manually by the operator by an electronic control lever (computer joy stick), the computer that generates motion commands executes the control by prohibited region (Franco *et al.*, 2007). This work will present a positioning system in which, the operator moves a table manually through a handle, as explained forward.

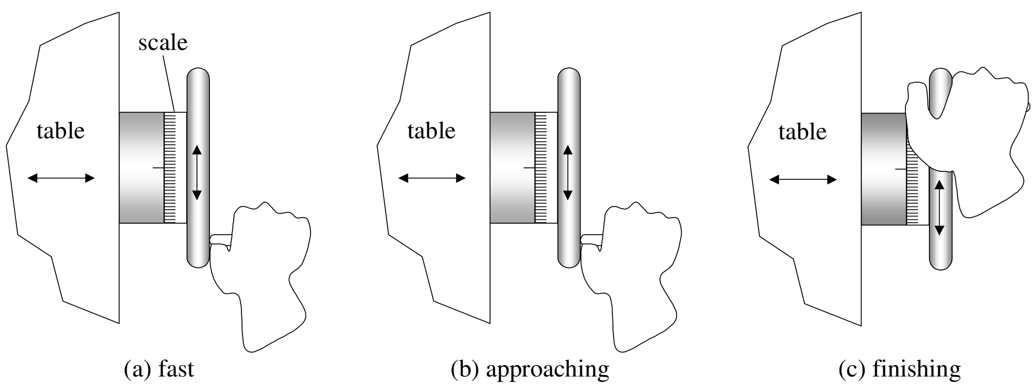


Figure 3. Steps in a manual positioning

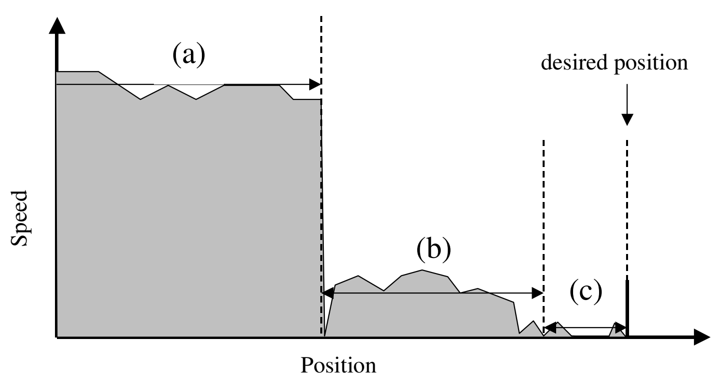


Figure 4. Speed in a manual positioning

## 3. THE HYBRID, MANUAL AND SERVO ASSISTED POSITIONING SYSTEM

The positioning system, named as the “hybrid, manual and servo assisted positioning system” or HPS, has mobility in a single direction. However, this architecture can be easily expanded to the motion in 3 directions, joining three identical systems, thus enabling the motion of a toll in the space.

Figure 5 shows schematic of the HPS, presenting its main components. The basis is a linear guide driven by a ball screw. At one extremity of the screw, a handle is installed and, at the opposite extremity, a position sensor. A computer, receives the desired position to be reached, samples the sensor signal, processes the signal according to a control algorithm, displays the actual position and sent signal to activate a electromagnetic brake.

When starting a positioning, the operator introduces in the computer, the desired position. Then, the computer starts a constant monitoring of the table position, displaying the actual position. Until the desired position, the operator can move the table freely through the handle. However, as the table approaches the desired position (prohibited region), the computer activates gradually the electromagnetic break. When the distance between the table position and the desired position becomes inferior to an admissible amount, the handle is completely locked. The brake is released only if the operator tries to move the table backward.

Once the positioning is completed, the control algorithm request operator to furnish a new desired position.

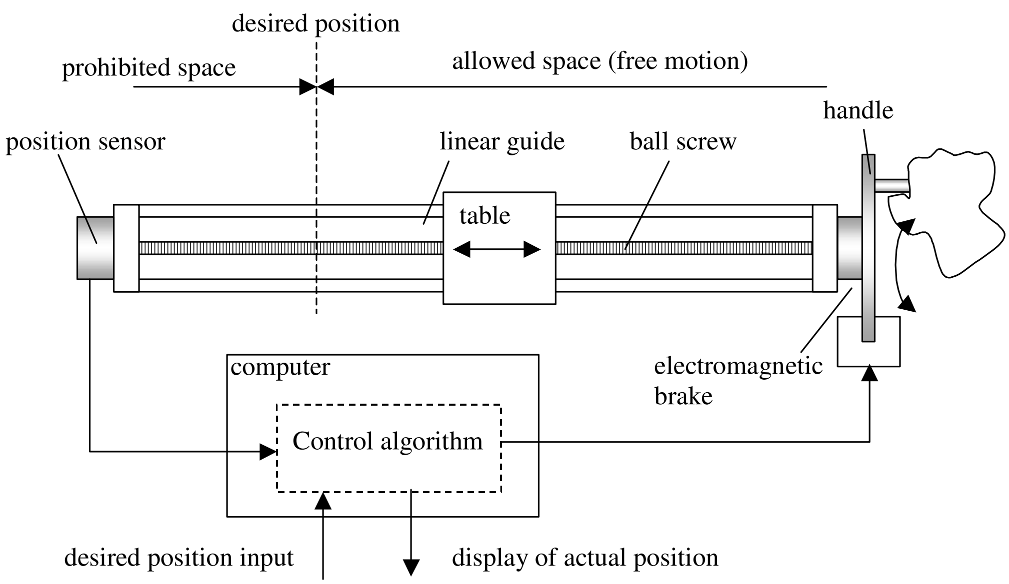


Figure 5. Schematic of the developed positioning system

## 4. PROTOTYPE OF THE HPS

According to the schema described above, a prototype was developed and tested. Fig. 6 shows photograph of the prototype. The prototype uses a 400mm stroke, ball screw (10mm/rev pitch) driven linear guide. An optical encoder with 650 pulses/rev resolution measures the table position. This enables computer to monitor the table position under a resolution of 0.016mm. Actually, the encoder used in the prototype has a resolution of 2500 pulses/rev. However this resolution is decreased to 650 pulses/rev since the digital interface is not capable of sampling so many pulses at an acceptable speed.

Figure 7(a) shows details of the electromagnetic brake. Two arms are pivoted in one side and, in the opposite side, have ferromagnetic cores set inside an electromagnetic. When the current flows in the electromagnet, these cores attract each other. Then, the break shoes fixed to the two arms are pressed against the handle wheel, generating the braking force. The brake is able to develop a momentum of 0.3N.m by supplying 3A to the electromagnet. This momentum showed to be enough to avoid any attempt of the operator to move the table. This force can be regulated though computer, in four stages, 0%, 50%, 75% and 100% of the maximum braking momentum.

Figure 7(b) shows detail of the intention sensor mentioned above. To detect the attempt of the operator to move the table forward or backward, the handle grip was installed so as to have a play with respect to the handle disc. Thus, with the handle locked, if the operator tries to turn the handle in one sense or another, a corresponding switch is turned on, indicating to the computer, the intention of the operator. Ideally, a force sensor should be used, however this solution is adopted for simplicity. According to this intent, the computer releases or keep the handle locked.

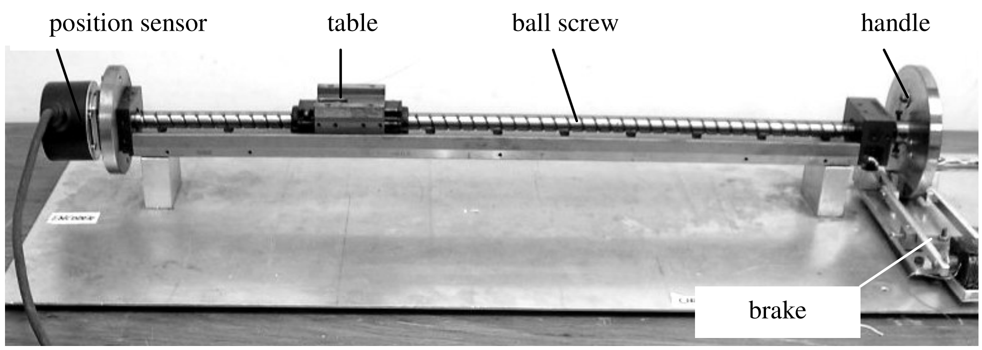


Figure 6. Prototype of the HPS

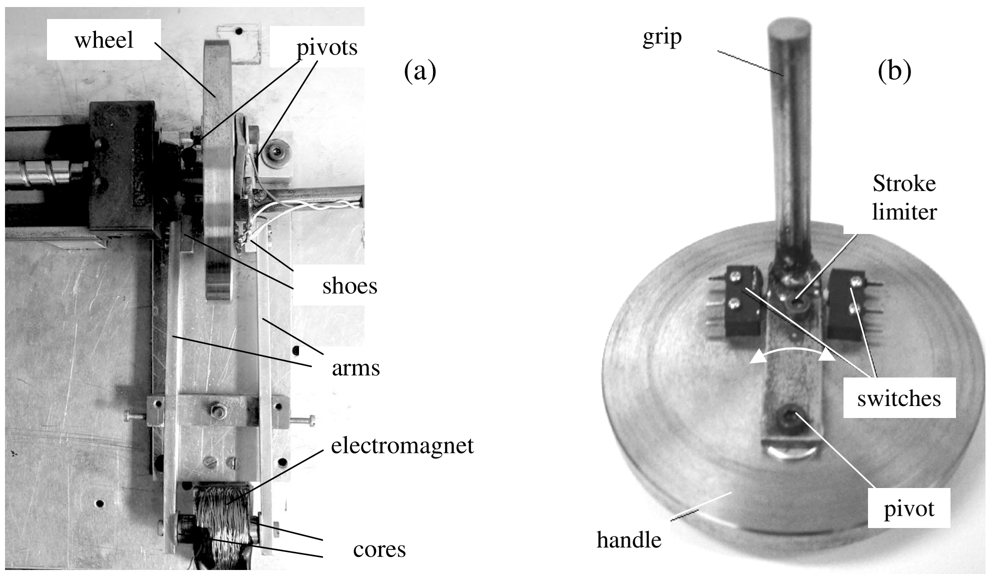


Figure 7. (a) Electromagnetic brake, (b) Handle with the intention sensor

Figure 8 shows the control algorithm of the PHS. The algorithm is set so that the brake is totally activated and the handle locked, if the difference between actual and desired position becomes less than 0.05mm. This was considered reasonable, since 0.05mm corresponds approximately to 3 encoder counts. In the same algorithm, A, B and C are bits that represents the level of braking force. For a distance larger than 5mm from the desired position, the braking force is 0%. For a distance between 2 to 5 mm, the force is 50%. For a distance between, 0.05mm to 2mm, the force is 75%. And finally, for distances of less than 0.05mm, the force is 100%.

## 5. RESULTS OF TESTS

The efficiency of the HPS is tested with the prototype. The user defines the desired position. For comparison, six different positions are defined: −50, −20, −10, 10, 20 and 50mm. These positions are relative to an arbitrary reference position around the middle of the slide table stroke. Although the handle is moved manually in the HPS, the operator tries to execute all positioning, moving the table with a speed of approximately 720mm/min. As expected, in all positioning tests, the table slows down as it approaches the desired position, stopping completely at the desired position. Tab. 1 shows results of these tests. Values of obtained position ($x$) shown in the Tab. 1, are mean values of 10 positioning repeated for each value of desired position. The average value of the obtained position is compared with the desired position. By this procedure, the accuracy of positioning by the HPS is evaluated. The average deviation of the obtained position from the desired one is of around 0.2mm. The table also shows the standard deviation of each test, showing the repeatability of the positioning. The positioning error is limited to values shown in Tab. 1 because of the resolution of the sensor (0.016mm), the brake that has only three levels of braking force and because of the very simple algorithm that is used to control the braking force. Results are not shown here, however positioning tests are repeated using a lower speed, of about 300mm/min. In this case, the average positioning error drops from 0.2mm (in the case of 720mm/min) to 0.05mm. Since the objective is to validate the control strategy, a very simple user interface was developed according to the description at the beginning of Section 3.

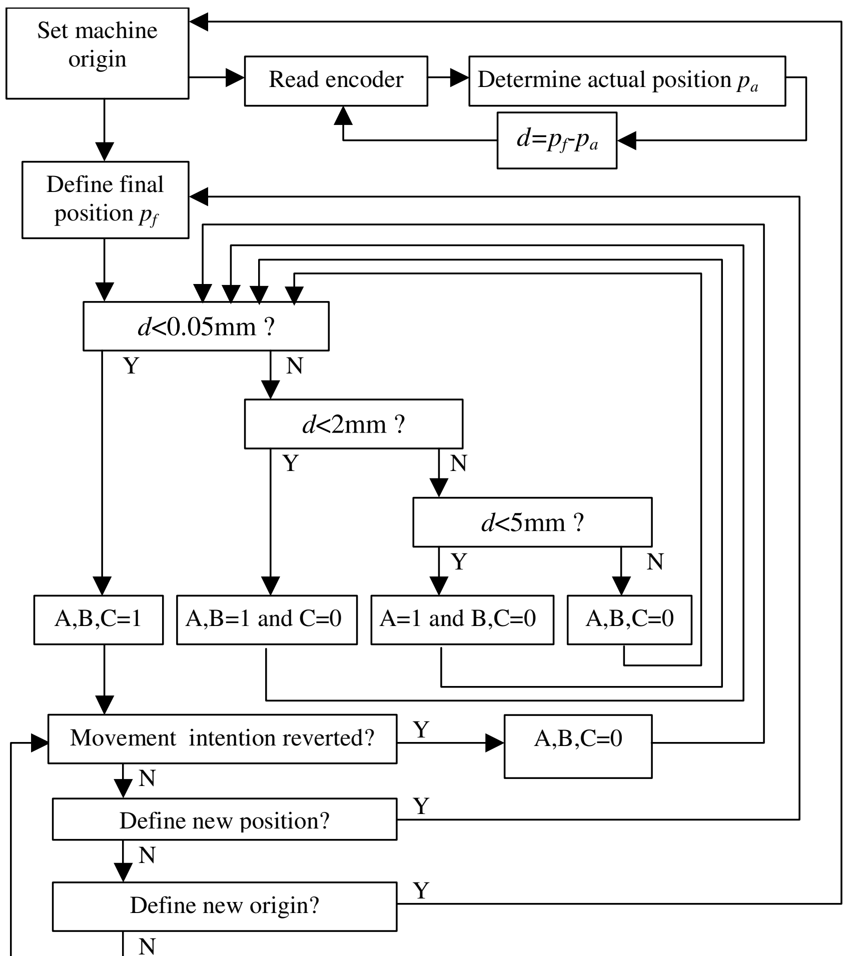


Figure 8. Control algorithm of the HPS

Table 1. Results of positioning tests

| | **Desired position** $(x)$ | | | | | |
|---|---|---|---|---|---|---|
| | **– 50mm** | **–20mm** | **–10mm** | **10mm** | **20mm** | **50mm** |
| $(\bar{x})$ **(mm)** | **–50.13** | **–20.26** | **–10.05** | **10.07** | **20.17** | **50.13** |
| $\sigma$ **(mm)** | 0.14 | 0.13 | 0.19 | 0.12 | 0.32 | 0.10 |
| $\lvert x-\bar{x}\rvert$ **(mm)** | 0.13 | 0.26 | 0.05 | 0.07 | 0.17 | 0.13 |
| $\lvert x-\bar{x}\rvert / x$ **(%)** | 0.26% | 1.29% | 0.46% | 0.70% | 0.87% | 0.27% |

A set of positioning is also executed in the HPS with the control turned on and turned off. In the HPS without control, i.e., in the manual positioning, instead observing the scale in the handle, the operator executes the positioning, observing the actual position presented in the computer monitor. When the difference between the actual position and the desired position becomes inferior to 0.2mm, the operator finishes the positioning. The value 0.2mm is determined since this was the error in the HPS. In terms of time demanded for the positioning, the PHS enables a faster positioning compared with the manual positioning. Tab. 2 shows the times demanded on each positioning. In the average, the positioning by the HPS was 1.3s faster than totally manual positioning. In the case of the desired position of 20mm, the demanded time in the HPS is about the half of that in the case of the manual positioning.

Figure 9 shows time by position graphs in the case of manual positioning (Fig. 9(a)) and, in the case of the HPS (Fig. 9(b)). The desired position is achieved faster in the case of the HPS. In the graph corresponding to the HPS, one can notice the action of the electromagnetic brake, and consequent speed decreasing, as the table approaches the desired position.

Table 2 Comparison of times demanded in the positioning

| **Desired position (mm)** | **Demanded time(s)** | | **Difference (s)** |
|---|---|---|---|
| | **HPS** | **Manual** | |
| **10.00** | 1.5 | 2.4 | 0.9 |
| **20.00** | 1.8 | 3.7 | 1.9 |
| **50.00** | 4.0 | 5.2 | 1.2 |
| **Mean** | | | **1.3** |
| | | | |

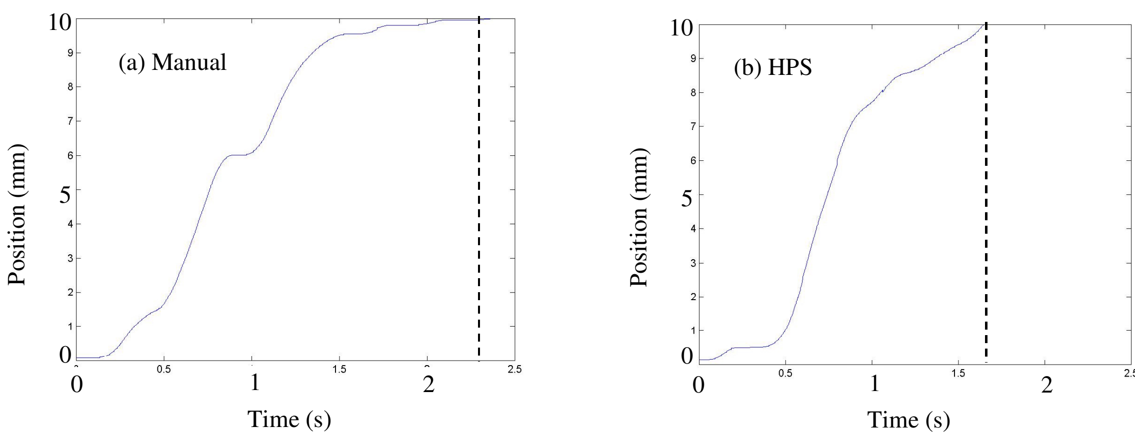


Figure 9. Position x time graphs

## 6. CONCLUSIONS

Aiming machines tool with productivity intermediate between manual machines and NC machines, this work presented a new control strategy in which, a human operator executes de position manually and a servo system helps the operator to execute precise positioning. Moreover, this work proposed the concept of prohibited region to control the position of a cutting tool. The proposed machine as well as the control, can be implemented in different manners but this work proposes an architecture composed of: a) a manually driven sliding table, b) a position sensor that monitors the table position, c) an electromagnetic brake that locks the handle when the table reaches the desired position and d) a computer that executes the control algorithm. A prototype is developed and constructed. By positioning tests, the effectiveness of the strategy is demonstrated. The system enables a fast and precise positioning of the table, with the operator driving the table through handles. Comparison with completely manual positioning shows that by the proposed strategy, a faster positioning is possible.

This work presented the prototype with motion in only one direction. This was done in order to validate the control strategy and show one of possible machine architecture to achieve the strategy. In future works, authors intend to develop prototypes with motion in more than one direction. However, even this model with motion in only one direction can be applied for example in the drilling of long and slim components. This is the case of structural elements of a tower, with lengths over than 10m, in which several numbers of holes must be drilled.

**7. ACKKNOWLEDGEMENT**

This project was conducted under grant from "Fundação de Amparo à Pesquisa do Estado de São Paulo - FAPESP" (SP, BRAZIL). Process no. 05/59963-6. Period of mar/2006 to april/2007.

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