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A BENDING CELL FOR SMALL BATCHES

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Abstract. *This article presents the study that is done for the conception of an automated bending cell devoted to the processing of parts in small batches, gathering the real necessities of potential customers. Joining the maximum of possible information, on the present cells, is has been able to conceive an automated bending cell devoted to the bending of parts, with different form, weight, thickness, etc., in small batches. To be able to reach the proposed objectives, the cell is equipped with auxiliary systems, such as ATC (Automatic Tool Change) allied to a tool warehouse, AGC (Automatic Gripper Change) with three different grippers, a reposition station, and a dedicated 7th axis in the press brake designed to dock a standard 6 axes robot, that provide to cell a sufficient grade of autonomy. Allied with the idea of creating a cell for small batches, is introduced the target of getting this cell at lower price as possible. Thus the cell acquires an extended application range very important for potential customers. To get real perception of the money saving when working with this automated bending cell comparisons between Man work times vs. machine work times in production of small batches have been made.*

1 INTRODUCTION

Sheet metal bending is a metal forming process wherein a sheet metal blank is bent by using tools with one or more pairs of punches and dies. Sheet metal parts are some of the most important semi-finished products. A few among the most common applications of sheet metal parts are automobile and aircraft panels, domestic appliance housings, electric cabinets etc. Customization of sheet metal parts to produce parts of various configurations and sizes is very common in a sheet metal fabrication scenario [1].

A growing demand of superior quality with a minimum cost is a fact. So, there is a tendency, for part of the manufacturers of these pieces, to replace specialized workers by automated bending cells. These cells are conceived with the objective to reproduce, as near as possible, the best work carried out by the Man, and so reach an effective cost reduction. So, the automated bending cells are a reality that comes associated to the production of a vast variety of products found in the market.

In general, bending cells are used to execute parts that are produced in large batches and with similar shape between them, or those that need two or more operators to handle the part [2]. Today, in order to offer flexibility, higher accuracy, better quality control, higher degree of automation, and improved productivity, machine tool manufacturers are combining material processing, material handling, and part positioning systems into single integrated manufacturing cells [3], turning the cells more dedicated to present needs.

In small batch manufacturing, one of the biggest problems is the frequent setup change that reduces the overall throughput of the manufacturing facility. To enable cost-effective small-batch manufacturing, we need new techniques to reduce the number of setup changes and try to automate them. In sheet metal bending, the time taken for the actual process of bending is significantly less compared to the time taken for setup and tool changes. Sheet metal bending press-brakes offer setup flexibility by allowing production of more than one type of part on the same setup [1]. In construction of single machines there is actually a trend to turn them more flexible by widening be the working length, turning possible the use of several working stations, be the stroke length, turning possible the use of different heights of tools.

With this in mind, it is demanded a high level of autonomy to the bending cells. To achieve this demand, automated bending cells should to be capable of switching tools and grippers automatically. Then we studied the incorporation of an ATC (Automatic Tool Change) system and an AGC (Automatic Gripper Change) system by using the robot power included n the cell.

To better understand the actual customer needs, we collected some examples of final parts from a typical potential customer for this kind of cell. An extensive study has been made to understand which components are vital to turn the cell sufficiently autonomous, and try to exclude those that can be suppressed, in way to get an automated bending cell, capable to do the work, at a low cost.

To achieve this target, we decided to get from market as many standard components as possible, reducing the manufacturing of special components and, as return, reducing the final price of the automated bending cell.

At last, but not at least, other important objective of the project it is to conceive an automated bending cell with an appreciable compactness, once it is a characteristic more and more appreciated by the buyers and by the manufacturers to reduce the installation costs.

2 AUTOMATED BENDING CELL – A NEED FOR ADIRA

ADIRA integrates the group of the principal manufacturers of machines devoted to the conformation, by bending, of sheet metal plates. It has a long history of automation solutions that can offer customers simple and efficient solutions to their problems, increasing their productivity and the respective profits.

ADIRA was the first manufacturer to conceive a system to assist the bending, launching the so called *bending followers*, which support and follow long sheet metal plates during the bending [4]. This system, as shown in figure 2.1, it is very useful when the press brake operator need to handle heavy and/or large plats.

Figure 2.1: Press brake ADIRA - QIHD with bending followers.

Also, ADIRA already have a medium automated bending cell that is able to cover a vast variety of customer necessities. This cell is composed by a standard robot (six axes), fixed in one additional eccentric axe (7^{th} axe) to give extra freedom to robot, enabling the multi-station bending and palletizing , an auxiliary manipulator, called *"sheet-feeder"*, responsible for acceleration of the plates feeding to robot, and a press brake. It is possible to get similar cells, in appearance and layout, but with different bearing load by changing the robot, if needed, and integrating it with a higher, or lower, tonnage press brake, adapting the costs of the final bending cell to the customer needs [4]. The cell is represented on figure 2.2.

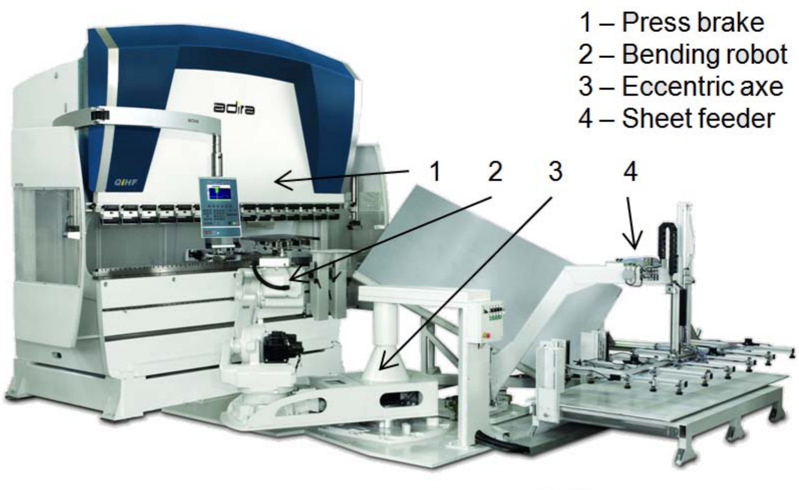


Figure 2.2: Bending cell - ADIRA.

But ADIRA wants continuously to improve his products and maintain a permanent innovation, in way to guarantee a continuous competition with other manufacturers. Due to this, ADIRA faces the necessity of building a new machine able to give answer to the necessities of potential clients, which want a fully autonomous machine, able to increase his profits in the production of short batches. This was one of the principal reasons, which motivated ADIRA to conceive this project by placing ADIRA, once more, in the head line of automated solutions for sheet metal bending industry.

3 CELL’S CONTROL

The main goal when the command part of the any workcell it is developed is to turn that cell the most independent possible of the operator. The programming/configuration of the workcell can be made by any operator. To reach this autonomy degree the workcell must be controlled as a single body. These points are very important to the future success of this kind of automated bending cell present in this paper.

Nowadays, the command part of the automated bending cell developed for ADIRA they are based in the numeric control CYBELEC ModEva 12S. The CYBELEC, which is in some way obsolete to be implemented in this kind of automation solution. Though, CYBELEC ModEva 12S, is capable of add extra axes, and functions [3], linking this numerical control to the robot controller MOTOMAN NX100, and reach a perfect “speech” between them would be a quite complex task to most customers, once the programmer must program in more than one language with different environments.

To avoid these limitations, the cell must be controlled by a software application developed in a high level programming language capable of control all the cell, enabling the offline programming, making possible a continuous production without long interruptions every time that costumers need to change de productions and its layouts.

The simpler solution to this problem, in our opinion, it is to eliminate the “obsolete” CYBELEC ModEva 12S, and let the press-brake control in charge of the MOTOMAN robot controller NX100 itself.

The NX100 controller is able to control a maximum number of 36 axes, it possess 40 digital inputs and 40 digital outputs, 40 analogue channels, as option, and thanks to the Advanced Robot Motion control system it is possible of synchronize the movement of all axes [4], turning possible to achieve a perfect and fast bending operation.

Once MOTOMAN already have a solution to offline programming of its controllers, the MotoBend [5], which is a program that use a high level programming language, it have a very good interface that makes very easy the operation planning. The MotoBend allow the creation of several environments, making possible to simulate the cell layout in perfect conditions, allowing the generation of an automatic optimal bending sequence, positioning of the back gauges, and choose a palletizing pattern. And it allow simulate the complete bending process and create robot jobs on the PC [6].

In sum, with this software it is possible to control the NX100, which it is in charge of control all the automated bending cell axes, getting a full and simple control of the cell in one only program language.

4 AN INTERPRETATION OF CUSTOMER NEEDS

As been told above, the needs of a typical customer were collected, in way to guarantee that the automated bending cell is able to give a positive response to all requirements, making it a viable purchase.

The contacted customer is a manufacturer of machines dedicated to food industry, making baking ovens, heat/moisture chamber and cold chamber. It produces several models with different characteristics (form, weight, thickness, etc.), so, in order to produce all components required to final assembly of one of these machines, it is necessary to produce to order small batches of parts.

As natural, some of the parts to bend are very different one from another and require several types of tool and grippers, in case of automated bending.

To perform all parts, an extensive study has been made for the selection of all the tools suited to the maximum number of parts [3,9,10,11] and for the bending simulation [3,9,10,12,13].

Next, it will be presented some specific examples of parts to be produced, the batches of each part and the necessary tool changes and parts handling.

4.1 Parts to produce

Table 1 shows some examples of the diversity of parts that the contacted customer needs to produce in order to assemble components to final machine assemblies. In table 1, are collected some parts to be bent, in order to integrate two subassemblies, called respectively, assembly 1 and assembly 2.

Also in table 1 are present the respective thickness, blank dimensions, the size of the batch, the number of bends, the regrip number, and the tool to get an overall perception of the distinguished characteristics of each part.

Assembly 1						
Part	Thickness [mm]	Blank dimensions [mm]	Batch size	Bends	Regrip	Tool set [Punch – Die]
1.1	1.2	787x72	4	4	1	BIU-023* - OZU-010
1.2	1.2	298x120	2	2	-	BIU-022 – OZU-010
1.3	1.2	297x72	4	4	1	BIU-023* – OZU-010
1.4	2	971x135	1	3	1	BIU-022 – OZU-011
1.5	2	704x259	18	4	1	BIU-022 – OZU-011
1.6	3	255x35	1	4	-	BIU-022 – OZU-012
1.7	4	492x179	1	3	-	BIU-022 – OZU-013
1.8	4	306x100	1	4	-	BIU-023* - OZU-013
1.9	4	274x123	1	1	-	BIU-022 – OZU-013
1.10	5	121x82	1	1	-	BIU-022* - OZU-014
Assembly 2						
2.1	1.2	934x113	12	4	1	BIU-063 – OZU-082
2.2	1.2	640x147	4	4	1	BIU-023* - OZU-010
2.3	1.2	578x523	3	4	1	BIU-022 – OZU-010
2.4	1.2	414x407	4	8	1	BIU-023 – OZU-010
2.5	2	464x80	4	3	1	BIU-021 – OZU-011
2.6	3	188x69	4	4	-	BIU-021 – OZU-012
2.7	3	97x20	2	1	-	BIU-022 – OZU-012
*Inverted punch setup						

Table 4.1: Some parts that will integrate assemblies 1 and 2.

4.2 Autonomy required to cell

To perform the bend process in all parts, with the desired autonomy, the automated bending cell needs to integrate several sets of auxiliary components, which assist the bending robot during bend.

As announced, one of major characteristics of the cell is to be dedicated to the production of small batches. Table 1, as already referred above, show examples of bending production in small batches, and in some parts, the batch reach the minimum quantity of one piece per batch. Satisfying this costumer need is really a challenge in terms of automation of the bending cell.

Accepted the challenge, it was concluded that the cell will need an automated tool warehouse, with several tools able to bend different shapes and thicknesses, and with the capacity of preparing the stored tool to be placed in the press-brake, when and where is needed, in way to reduce the tooling setup time. Then, become clear that the robot could used set with an extra axe to extend the robot arm range and transport the tools from the warehouse to the front of press-brake and put them in the respective beams. To reduce the auxiliary automated components, in order to lower the final price of cell, the use the bending robot to complete the task was an entry.

Due to the variety of final shapes of the different parts to bend, it was realized that the cell must be equipped with more than one gripper, to allow the handling of all parts. Once more, an auxiliary station will be necessary to couple the grippers when these are not being used. So once more, it was used the flexibility of the bending robot, to make the change, reducing the automation level of the grippers changing station, reducing even more the final price of automated cell!

As others automated bending cells, this will need to have a repositioning station, where the bending robot can place temporarily the sheet metal, in order to perform the necessary regrippings necessary to avoid interference with bending process.

At last all these contribute to the decision on the adoption of a linear 7^{th} axe, which will provide the necessary linear movement to the bending robot offering extra flexibility by the widening of the range of the working field.

All the auxiliary systems will be detailed in the next chapter, showing how all this systems work together in way to reduce the part process times, and give a close look in each one.

5 SOLUTION FOUND

In this chapter are describe all the auxiliary systems that were conceived to assist the bending robot during bending process. And it will be shown how each system works to get a minimum bending time.

It will be also justified the choice of some components, that contribute more for the objective of lowering the cost of the automated bending cell.

To get a global view of the conceived automated bending cell, a picture is showed in figure 5.1 that includes all the mentioned auxiliary systems.

The cell, as can be seen in the figure 5.1, is composed by a press-brake, a bending robot, mounted on a linear track, responsible for the loading and unloading of the work pieces, an ATC system composed by an automatic tools warehouse, a tool shuttle, and the bending robot itself, an AGC system composed by three different grippers. The bending robot with its flexibility is capable to do the tool and griper change and place the work piece in the repositioning station to re grip them later on.

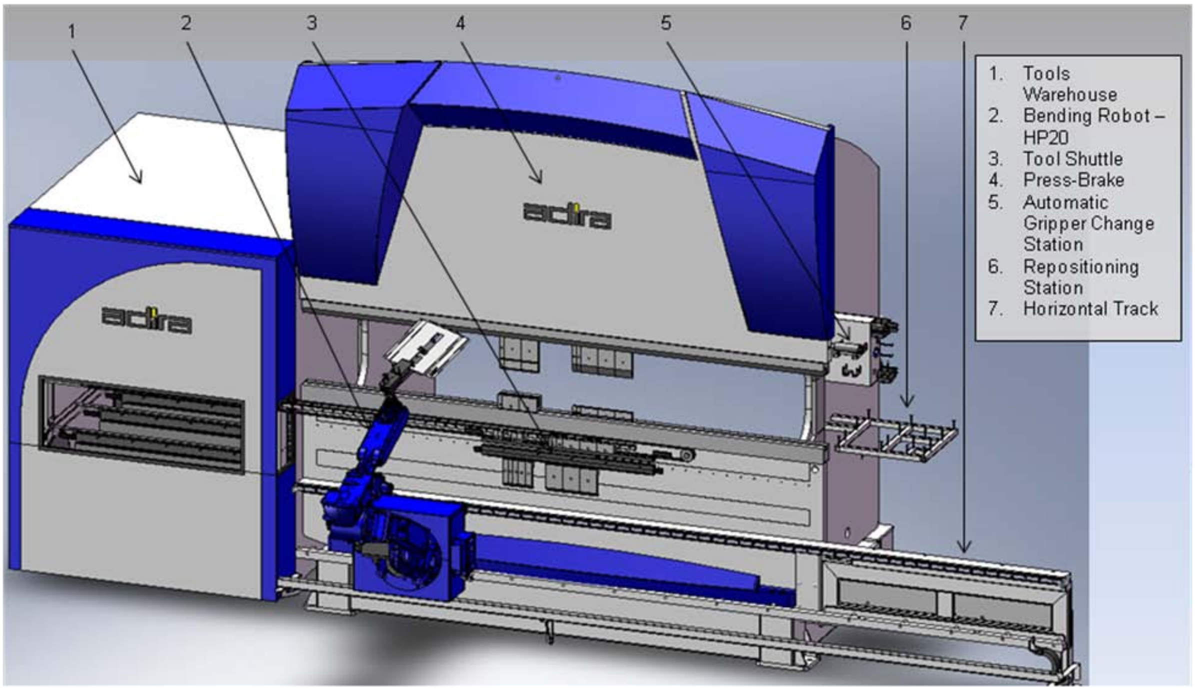


Figure 5.1: Automated bending cell configuration.

5.1 Bending robot

The robot chosen to incorporate the cell was the HP-20, a standard robot, from MOTOMAN. It is a robot with a bearing capacity of 20kg. It is mounted directly at the track attached to the press brake's lower press beam. It is capable of lateral linear movement, due to the linear track. Because it is used a *wall mounted* configuration, the S-axis is limited in its range, reducing its movement from ±180º to ±30º [13].

Due to the extreme flexibility of robot, the loading of the sheet blank and unloading of the final work piece is made by the robot itself. Depending on the sheet thickness, the blanks, can reach the sizes over 1500x500 mm, on rib bending, and nearly 800x800 mm on box bending.

Figure 5.2 shows the relation between blank size and sheet thickness (note that in figure 5.2 the limit of 1500 mm for the length was stipulated as maximum bending length proposed for the cell, and the relations presented are for the robot handling capacity. These relations cannot be fully applied in bending situations either to possible interferences with press-brake during the work piece handling, or to limitations on the robot range in work pieces with excessive width).

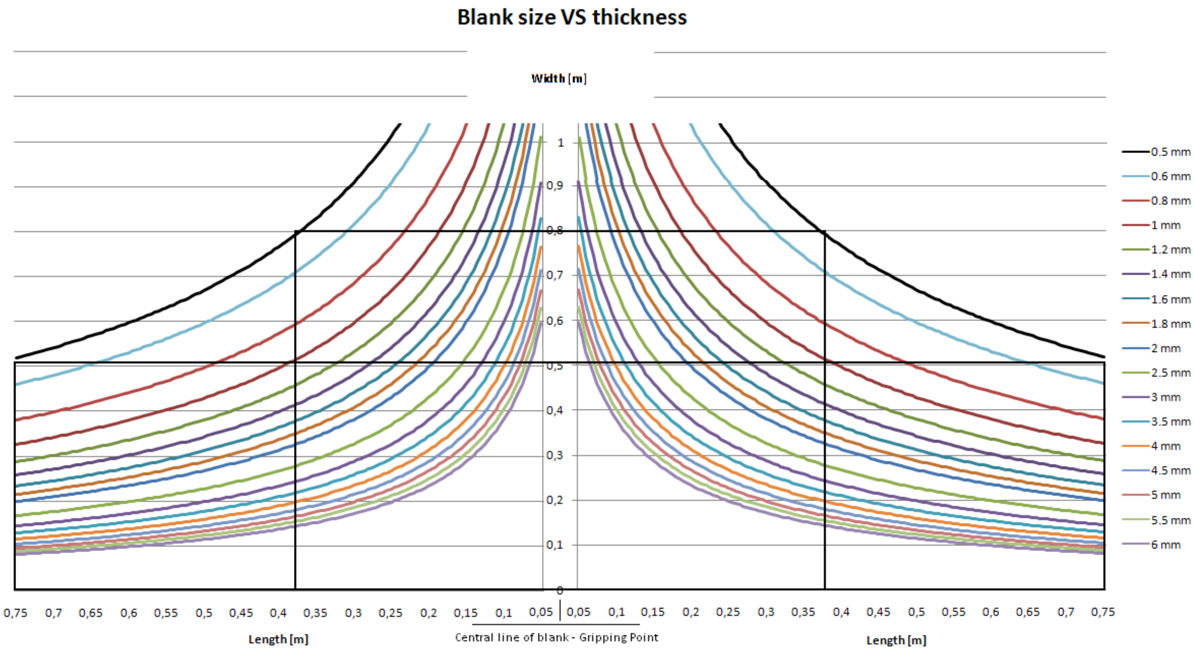


Figure 5.2: Relations between blank size and its thickness.

5.2 Automatic tool change system (ATC)

As told earlier, the ATC is a set of components that work together to change the tools in a fully autonomous mode.

The automatic warehouse is a system which stores the several tool docks, storing 22 die docks of 1000 mm each, in the upper part, and 12 punch docks, also, of 1000 mm each, in the lower part. This configuration is better suited to the tools shuttle characteristics, which, in order to get a maximum space saving on press-brake front, supports the punches in the bottom and a more common punch locking system (WILA) can be used, and the dies are placed in the top part (figure 5.3a). When needed the ATC enable a punch inversion by rotating the lower part of the tool shuttle, as shown in figure 5.3b inside the warehouse. This is why the automatic tools warehouse has an opening on front side.

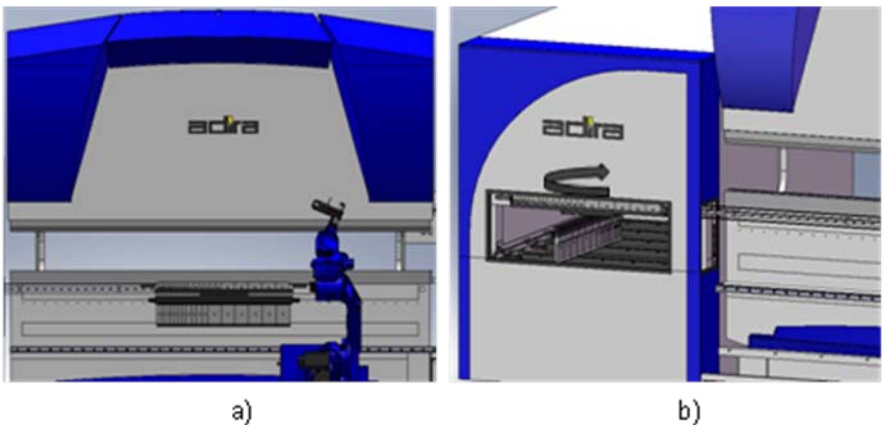


Figure 5.3: ATC; a) Tools transporter placed on press-brake front; b) Tool inversion.

To finally place the tools, the bending robot is used with the WILA ATC-G6 system that suites the handling of special WILA tools (figure 5.4). The ATC-G6, is docked in the AGC station, and can be switched by the robot itself, due to a pneumatic chuck system (SCHUNK) for quick module change. This switching is demonstrated on figure 5.5.

WILA tools can be purchased in several segments widths (20, 25, 30, 35, 40, 100, 200, and 515 mm), but the special tools, which are used in this cell, only are available in sections from 20 mm to 100 mm, due to ATC-G6 loading limitations, which is limited to a max tool weight of 15 kg [14].

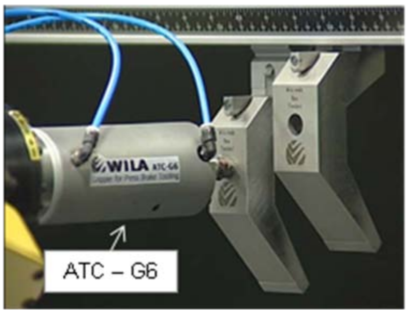


Figure 5.4: WILA automatic tool changing system – ATC-G6.

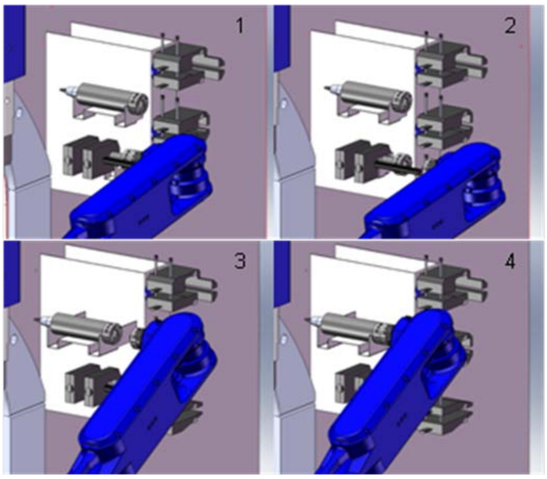


Figure 5.5: Switch to ATC-G6: Shunk system - SWS-011.

When the ATC-G6 is locked, the tools are placed in the desired positions as represented in figure 5.6. After finalizing the change of the tools set and their alignment, which is made by the robot itself in few seconds (this task made by Man takes a substantial time), the robot switch again to the sheet metal handling, being ready to start bending, after coupling of one of the grippers.

Please note that to accelerate the tools changing process, the tools shuttle, placed itself in the front of the press-brake, repositions the next tools while the bending robot is switching to tools handling gripper, ATC-G6, to accelerate the tools changing process.

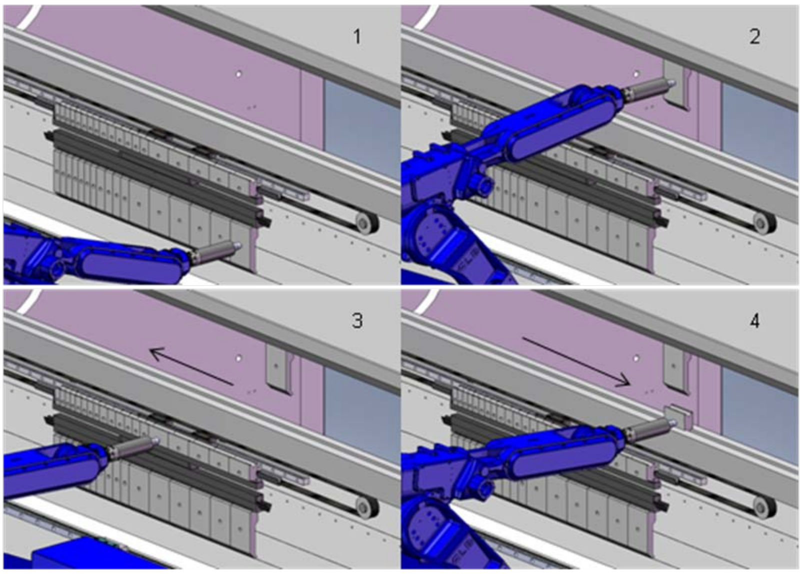


Figure 5.6: Tools setup with ATC-G6, evidencing the useful linear travel in 7^{th} axe.

5.3 Automatic gripper change system (AGC)

AGC system is the set of suited components that collaborate to achieve a fully automated gripper change.

The automated bending cell has three mechanical grippers, enabling the handling of a large variety of workpieces. It has a gripper indicated to the handling of larger workpieces, which has a gap, to allow the gripping of workpieces bended in the extremes. It has another one, with similar characteristic, but devoted to smaller workpieces, which do not allow for the use of the bigger one. At last, the cell has one gripper devoted to handle workpieces either small, or with particular profiles, which cannot be handled with none of the previous ones.

The system is very simple, which provides a low manufacturing cost and the reduced number of components needed, allow a precious money saving.

AGC involve the use of the bending robot to reach the switching station. Then the switch is made, once more, by the robot, which has a major importance in these systems. The robot docks the last gripper in is docking station, docking then the desired gripper (in figure 5.7 is represented this sequence). The locking of grippers to the bending robot is pneumatic by using a system provided with two little pneumatic cylinders.

The grippers are guided by three bars, one in the main block, and the other two on the grippers itself, guaranteeing a perfect positioning of both parts of gripper.

The grippers, as shown in figure 5.8, are composed by two parts. The first one, on left, is the part that is going to be locked at the main block, and it is the part where bars are used to guide while be attached. The second part, on the right, is the gripper clamping part that goes to do the gripping action. We decided to make this separation, to allow customers to acquire different gripper clamping profile, as they needed, without a complete construction of this set, saving time and money.

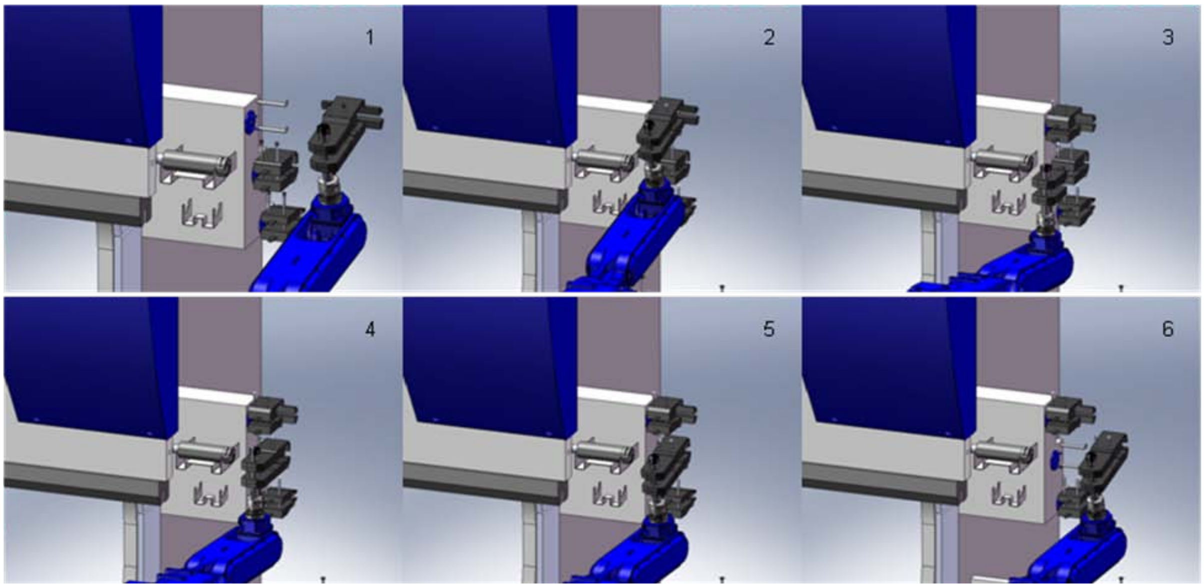


Figure 5.7: Automatic gripper change example sequence.

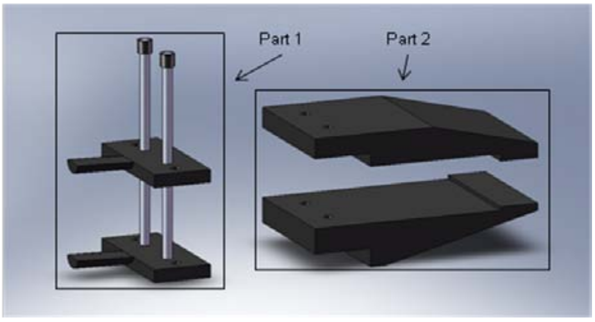


Figure 5.8: Gripper parts.

5.4 Repositioning station

The repositioning station has a vital importance in automated bending. As we can imagine, the sheet metal manipulators, used in any automated bending cell, are limited on the parts handling. So there will be times that the robot will not can perform the bending operation, due to physical interference. To get over this problem, bending cells have to be equipped with this station, which can have a lot of different configurations in different cells, that provides a place where sheet manipulators can dock the workpiece during the regripping time.

So to get these results, the collected parts from model customer have been studied to specify a geometry which will fit in all parts that will need to be regripped. The station “locks” the workpieces due to pneumatic couples.

To view how this station is really necessary, we show on figure 5.9a workpiece that need to be regripped in order to finish bending sequence.

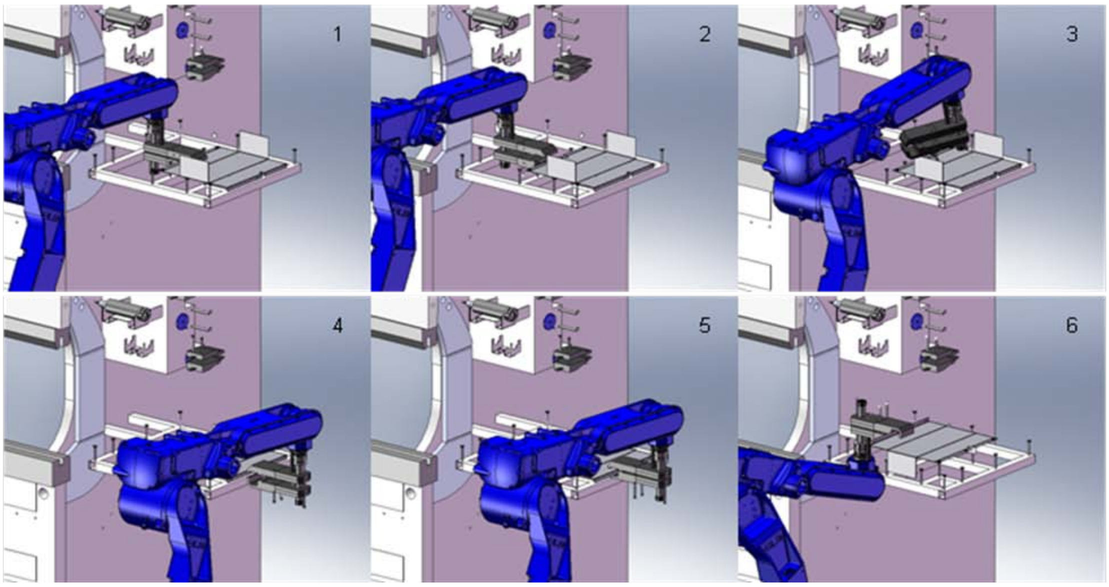


Figure 5.9: Regripping of workpiece.

5.5 Seventh axe

The last item that will be analyzed is the 7th axis. Usually, this "extra" axis is implemented in several bending cells. However, the axis configuration, can be very different from cell to cell, they can be mounted on ground, mounted on wall, can be an eccentric rotary platform, as seen in ADIRA's bending cell, showed in figure 2.2.

To turn the automated bending cell as smaller as possible, the wall mounted configuration for the seventh axis was chosen, saving a substantial space on press-brake front.

This axis was conceived to provide a high level of freedom to the bending robot. With this 4.5m length axis, the robot can integrate the ATC and ACG systems, performing a crucial part in both processes, as seen above, turning possible the construction of a very simple repositioning station, and enabling a quick and precise tools setup. Also, with this axis, it is guaranteed that the cell will be able to perform a quick multi-station bend, as it is represented in figure 5.10, which is a crucial characteristic to any automated bending cell be succeed.

In figure 5.10 it is represented the bending process to achieve the final configuration of a part used as a dock land to laptops, which is presented in its final form (unfolded) and in its initial form (folded) in figure 5.11. To perform all the bending process two sets of tools are used, one to perform the V bending (figure 5.10-4) and other one to perform the hammer bending (figure 5.10-1/2).

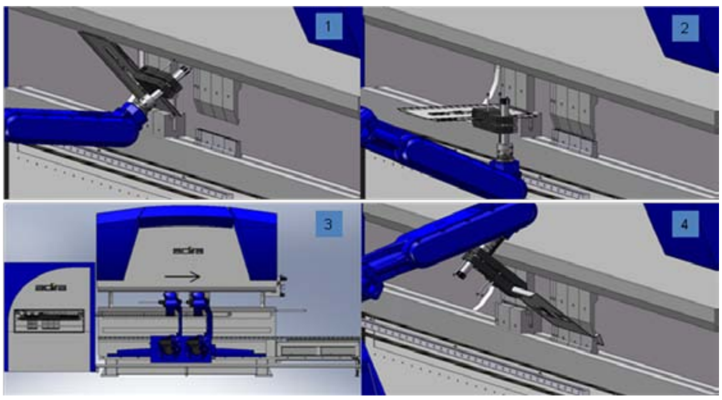


Figure 5.10: Multi-station bending operation.

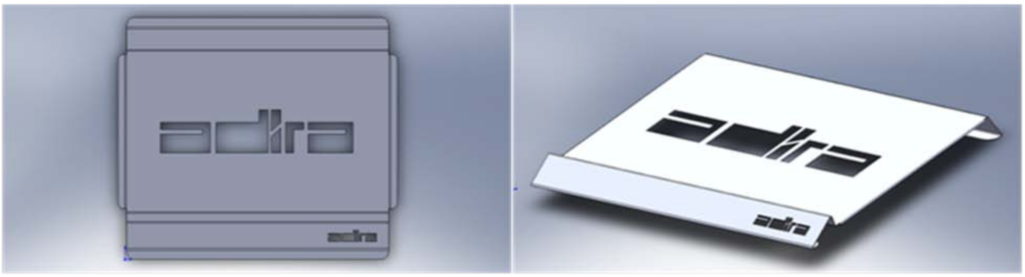


Figure 5.11: Dock land to laptops: a) Unfolded; b) Folded.

It is very important the option that the seventh axis offers to the customers, which can choose to drag the bending robot to the right side of the track, like is showed in figure 5.12, and perform manual bending, with an operator, but with the option of use, partially, the ATC system, once the WILA special tools allow the manual handling. With the help of the ATC, even manual work gets faster than “normal” manual bending processes.

To get a theoretic approach of the work times is necessary to calculate all the movement equations that will be applied to the seventh axis.

The first step to get the results is to choose the motor and the respective reduction. So it was decided to adopt a servo-motor model, with a respective gear box, which is already used by ADIRA, reducing the purchase cost, and get some benefits in the already reached know-how in the setting of this model.

In table 5.1 are presented the several variables that will be used to determine the travel times.

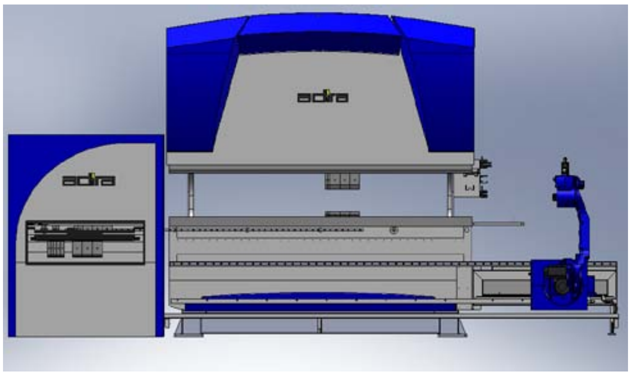


Figure 5.12: Manual bending configuration.

Designation	Units	Value
Mass [m]	kg	300*
Max. torque [T]	Nm	14.7
Max. rotation speed [ω_1]	rpm	5000
Transmission relation [i]	-	25
Transmission wheel ray [r]	m	0.05
Overall system efficiency [η]	%	85

*This value is the approximate weight of all robot set.

Table 5.1: Initial variables in order to determine the travel times in seventh axe.

In order to achieve all the movement equations, a basic scheme (figure 5.13) has been made, where are represented the mass to move (m), the transmission wheel radius (r), the gear box reduction ratio (i), the motor, and the input and output rotation speed, w_1 and w_2, respectively.

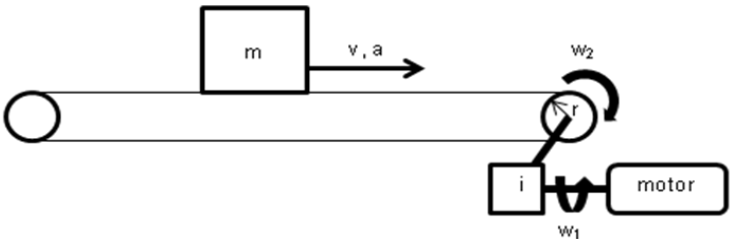


Figure 5.13: Basic scheme of the system.

To get the final travel times, the Newton law (1) was used, and by using the principle of Energy Conservation we arrive to equation (2).

$$F = ma \tag{1}$$

$$T\omega_1\eta = Fv \tag{2}$$

From (3) and (4) comes the linear velocity v (5),

$$\omega_2 = \frac{\omega_1}{i} \tag{3}$$

$$v = r\omega_2 \tag{4}$$

$$v = \frac{r\omega_1}{i} \tag{5}$$

Now substituting these values in equation (2) force F is determined based on known variables (6).

$$F = \frac{T\eta i}{r} \tag{6}$$

Knowing the force and de mass, the acceleration a (by supposing it constant) in equation (7) is,

$$a = \frac{F}{m} = \frac{T\eta i}{r} \tag{7}$$

Since,

$$a = vt \tag{8}$$

To determine the lapsed time until achieving the maximum velocity in equation (8) the acceleration time as t_a is in (9).

$$t_a = \frac{v}{a} \tag{9}$$

At maximum velocity (10),

$$t_a = \frac{v_M}{a} = \frac{m\omega_M r^2}{T\eta i^2} \tag{10}$$

In equation (12) it is represented the deceleration time (t_d), where d is given by (11).

$$d = \frac{Ti}{m\eta r} = \frac{a}{\eta^2} \tag{11}$$

$$t_d = \frac{v_M}{d} = \frac{v_M \eta^2}{a} = t_1 \eta^2 \tag{12}$$

In figure 5.14, it is represented the velocity vs. time graphic, which will give the relation between lapsed time and the complete travel by calculating the areas below the graphic.

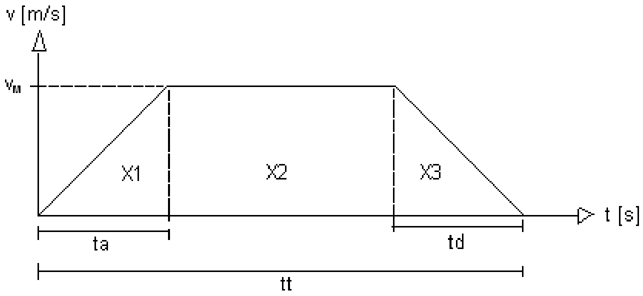


Figure 5.14: Velocity vs. time graph, reaching the maximum speed.

Now the total lapsed time (t_t) is calculated by defining the final travel (x_t).
The expression (13) gives the total travel, x_t.

$$x_t = x_1 + x_2 + x_3$$

$$x_t = \frac{t_a v_M}{2} + (t_t - t_a - t_d) v_M + \frac{t_d v_M}{2} \tag{13}$$

Evidencing t_t from (13) the equivalent expression (14) is:

$$t_t = \frac{x_t + \frac{t_a v_M (1+\eta^2)}{2}}{v_M} \tag{14}$$

With this expression, the travel time can be calculated. But it should be kept in mind that sometime the maximum speed will not be reached, as in small travels. Thus, the final travel time (t_t') in this conditions will be predicted

In figure 5.15, it is represented a similar graph to the figure 5.14 for this last condition, where v' it is the velocity value lower than v_M, the

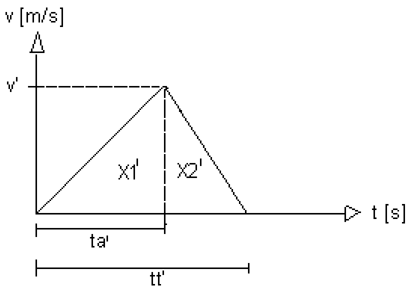


Figure 5.15: Velocity vs. time graph, when the maximum speed is not reached.

This situation happens when $v' < v_M$, and in these conditions:

$$x_1' = \frac{v' t_a'}{2} \tag{15}$$

$$x_2' = \frac{v'(t_t' - t_a')}{2} \tag{16}$$

And by summing (15) and (16) the total course x_t is shown in equation (17),

$$x_t = x_1' + x_2' = \frac{v' t_t'}{2} \tag{17}$$

Equaling the (18) and the (19) for v' expressions t_t' comes from expression (20), and then by making the substitution on (17) t_a' equation (21) is got.

$$v' = a t_a' \tag{18}$$

$$v' = d(t_t' - t_a') = \frac{a}{\eta^2}(t_t' - t_a') \tag{19}$$

$$t_t' = t_a'(1 + \eta^2) \tag{20}$$

$$x_t = \frac{t_a'(1+\eta^2) a t_a'}{2} \Leftrightarrow t_a' = \sqrt{\frac{2x_t}{a(1+\eta^2)}} \tag{21}$$

By making the substitution in (20) and in (18) comes respectively:

$$t_t' = \sqrt{\frac{2x_t}{a(1+\eta^2)}}(1 + \eta^2) \tag{22}$$

$$v' = a\sqrt{\frac{2x_t}{a(1+\eta^2)}} \tag{23}$$

In these conditions it is simpler to say that these last expressions must be used to get the travel time, when $x_t < 0.0476$ m, which it is the value that turns the equation (24) true.

$$v' = v_M \tag{24}$$

6 COMPARING MAN VS. MACHINE

The comparisons will be made in the production of a few parts. These comparisons will be made using theoretical results, by applying the movement expressions, and using already known data, of some routine times, against the worker time in a normal bending operation. The parameters that will be counted are the tools setup change time, and alignment, the bending operation itself, that will depend of the press-brake work time (this time it is equal to Man and robot operation), the workpiece handling time between bends (in the case of the robot, this times will be larger when a regripping on repositioning station is needed), and finally the loading and unloading times.

To get the operation times, the movement expressions for seventh axis were used, but also the robot movement times had to be calculated by using the speed axes information [14], and measuring the angles that each used axis will take at precise moments. To clear this picture, figure 6.1 shows a sequence of four pictures, which are simulating the punch setup (in order to make easy the picture reading we replace the robot by linear segments).

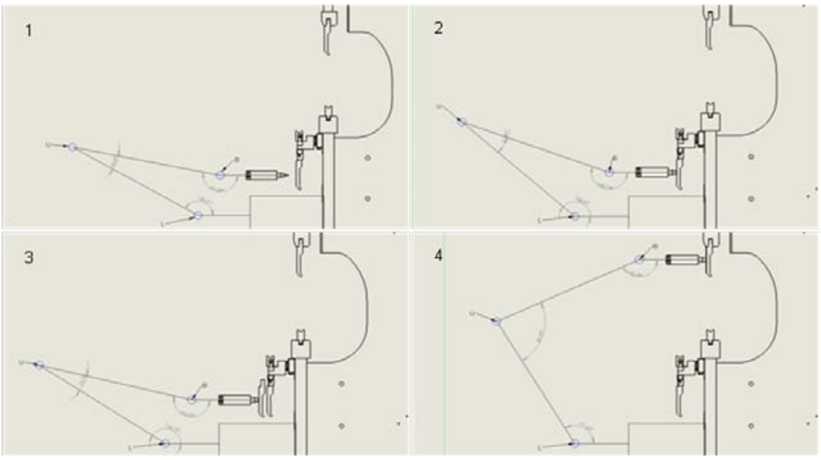


Figure 6.1: Simplified scheme of punch setup.

In table 6.1 are collected three parts, which are going to be used as example to comparisons of operation times between automated bending cell and Man Operation. In the table 6.2, are presented the several times spent in each task during each workpiece production.

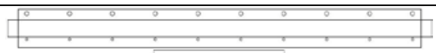
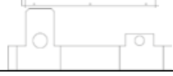
Part	Unfolded blank
1.1	
2.3	
2.6	

Table 6.1: Collected parts, from table 4.1, in order to perform the machine vs. Man comparisons.

	Automated bending cell			Man		
Task [s]	Part 1.1	Part 2.3	Part 2.6	Part 1.1	Part 2.3	Part 2.6
Load and positioning	7.148	7.148	7.148	8*	8*	8*
Bending	16	16	16	16*	16*	16*
Workpiece repositioning	5.697	8.366	-	-	-	-
Tools setup	118.713	88.713	22.713	200*	150*	46*
Unload	4	4	4	5*	5*	5*
∑ times (fist workpiece) [s]	151.558	124.227	49.861	229	179	75
Total time (batch) [s]	250.093	230.769	131.305	345	266	162
*We do not take into account the time spent in working and resting breaks						

Table 6.2: Tasks times in bending operation with automated bending cell and with Man.

7 CONCLUSIONS

- A complete automated bending cell was designed with an extreme flexibility, allowing the sheet metal bending with thicknesses from 0.5 to 5 mm and suiting the handling of several shapes of workpieces, and all this with tools and grippers changes in a fully automatic way, letting the Man intervention only in the production plan programming.
- The target of including the maximum number of standard components as possible, in way to get a final price lower than most cells in the market, was also reached, without arm the desired compactness of all automated bending cell.
- Next table 7.1 presents the technical specifications of the automated bending cell:

Bending robot	
Model	HP-20
Drive Motors	6 AC servo motor + 1 external AC servo motor
Max part size	1500x500 mm (rib bending); 800X800 mm (box bending)
Thickness	0.5 – 5 mm
Max part weight	10 kg
Repeatability	±0.06 mm
Gripper specifications	One touch pins
Power consumption	2.8 kVA
Power requirements (NX100)	3-phase, 240/480/575 VAC at 50/60 Hz
Robot weight	300 kg
Press-brake	
Model	QIHF-11030
Max. Capacity	1100 kN
Max. work length	3050 mm
Distance between housings	2600 mm
Throat depth	500 mm
Max. stroke	300 mm
Max. open height	500 mm
Approach speed	200 mm/s
Work speed	9 mm/s
Return speed	140 mm/s
Motor power	11 kW
Hydraulic oil capacity	280 l
Dimensions [LxWxH]	3100x2140x2870 mm
Machine weight	10500 kg
ATC warehouse	
Drive motors	5 AC servo motors
Punch dock large	1000 mm
Die dock large	1000 mm
Max. number of punch docks	12
Max. number of die docks	22
Dimensions [LxWxH]	1570x2000x2130 mm
Automated bending cell	
Dimensions [LxWxH]	6130x2550x3210 mm

Table 7.1: Automated bending cell technical specifications.

- By calculating the task times, it was possible to confirm the idea of conceiving an automated bending cell that works faster in small batches than Man does, demonstrating the importance that the tools transport/storing/change have, in task time, when constant changes of the tooling sets are required.

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