A ROBOT FOR FIBER INSERTION IN A PROFILE

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Abstract: *In this paper we present a robot built for the insertion of a large amount of optical fibres in profiles. The large amount of fibres to be inserted into the profiles lead to the need of automation of this process. The main original task of the robot relies on the manipulation of 1 mm diameter plastic optical fibres to be introduced in special plastic channels, the profiles, without destroying the fragile cladding of the fibres. We present the design and construction of the robot, its functional description, the automation solution choice and implementation, and the achieved performance results.*

Keywords: Sensors, Manipulation, Robotics, Automation, Systems Design.

1. INTRODUCTION

1.1 The ATLAS Experiment

Worldwide more than 1800 physicists from 35 countries are working on one of the biggest experimental set-ups in physics, the ATLAS detector at the CERN laboratory. ATLAS will be put into action with the most powerful accelerator of the world, the Large Hadron Collider (LHC).

The LHC will be operational in 2007 and will create conditions like those a fraction of a second after the big bang. For general information about the goals of this large experiment, a must see movie can be found at http://atlas.ch/movie/index.html.

1.2 The Process

The TILECAL calorimeter is the barrel hadronic calorimeter of the ATLAS detector, one of the two general-purpose detectors that will operate at the Large Hadron Collider (LHC) at CERN.

The TILECAL calorimeter is made of steel as absorber and scintillating tiles read out by WLS optical fibres as active material [Saraiva et. al. 2004], [David et. al. 2004]. The fibres are made of polystyrene doped with fluors emitting in the green region and are protected with a 30 μm thick cladding. The fibre diameter is 1 mm and the lengths are in the range from 0.8 to 2.3 m. The number of Wave Length Shifter (WLS) optical fibres to be installed is of the order of 550 000. The number of different combinations of fibres with different lengths needed to cope with the requirements of the TILECAL was of the order of 30. Due to the repetitive and monotonous nature of this task, automation is the adequate technology to be used. A feasibility study concluded for the viability of partially automation of the process of installation of the WLS optical fibres. The technical solution adopted as baseline assumes that the WLS optical fibres are supported by a special plastic channel, named profile, into which they are inserted by a robot-handling machine. These special profiles are then assembled in the grooves between the iron master plates of the TILECAL calorimeter modules.

The overall process of WLS optical fibre installation into the TILECAL calorimeter will be done in three phases.

• First, the insertion of the WLS optical fibres into the special profile.

• Secondly, the insertion of the profile with the WLS optical fibres inside into the grooves of the modules.

• Finally, the bundle and routing of the WLS optical fibres into the respective photodetector (Photomultiplier).

Only the first phase corresponding to the insertion of the WLS optical fibres into the special profile was automated. The other two phases were much less demanding and also the cost associated to the automation of these two phases was prohibitive.

There was interest on automation this process because it would be very expensive and difficult to find motivated staff to insert more or less 160.000 profiles with 3 or 4 fibres each. Considering 12 minutes for each profile (less than 4 minutes for each fibre) it would require near 20 Men.Year to fulfil the task, without considering the control quality costs.

The process of inserting of the optical fibres into the special profile is shown in Figure 1.

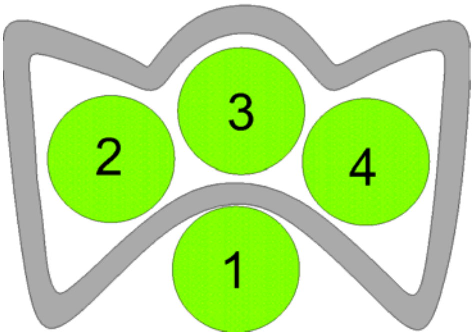

Figure 1: Insertion of the fibres into the profile

Figure 1 shows the fibres (in green) as they should be positioned along the profile. Each fibre will have a given length and must penetrate in a specific profile hole. Fibres are sensible and cannot be bended to radius smaller than 5 cm, so the robot must deal with them very carefully.

After an extensive bibliography search no similar work have been report on this matter.

Figure 2 presents a general view of the robot built to perform this task and Figure 3 presents the actual implemented robot.

Figure 2: A general artistic view of the robot

Figure 3 : Implemented machine general view

2. THE ROBOT FOR FIBRE INSERTION

The mechanical design of the robot took into account that the fibres could not be bended to radius smaller than 5 cm. Moreover, the friction was reduced the minimum to avoid destroying the fibre cladding.

The robotized machine for fibre insertion into the special profile is made up of several distinct components:

- Drums for fibres storage
- Cartesian manipulator system for picking fibres
- Fibre advance mechanism
- Insertion table
- Head cap of the insertion table
- Control system

2.1 Functional description of the built robotized machine

2.1.1 Drums for fibres storage

The fibres for insertion are stored in four cylindrical drum stores. Figure 4 presents a lateral and rear view of one of the four storage drums storing fibres of different sizes.

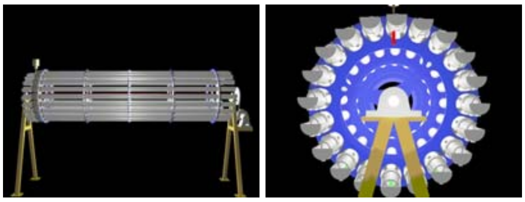

Figure 4: Lateral and rear view of the drums

Theses drums are mechanical devices made up of 20 tubes, with axial axes are on a cylindrical surface. The group composed of these tubes is jointly moved in turn of the axial axe of the cylindrical surface, by an electrical AC motor, with controlled speed and position. Figure 5 shows one of these motors which are located on the rear part of the drums.

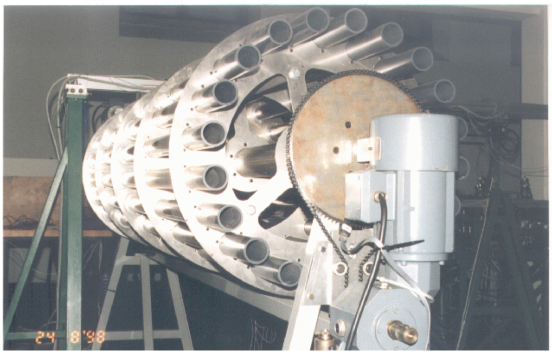

Figure 5: An electrical motor moves the set of tubes around the axial axe of the cylindrical surface.

The individual tubes of these drums are used to store different lengths of fibres. Each of these tubes has a capacity to store more than 100 fibres.

For a particular fibre insertion the control system moves the drum storage to place the appropriate tube (containing the pre-specified length of fibre to be inserted) in the top position. An encoder and a controller are used to control the motion.

The motor is a small single-phase induction AC electrical motor with a rotor with a squirrel cage design. The AC controller provides variable speed proportional to an analogue input of the controller. The Robot controller has a DA card to transmit the controller the analogue signal that will make the motor move.

The encoder is connected to an encoder reader card of the robot controller. When the cylinder of drums achieves the desired position (the position that corresponds to the length of the fibre to be inserted) it stops the motor.

At the beginning of each cycle, the four drums independently move to the position that corresponds to the length of each fibre to be inserted.

2.1.2 Cartesian manipulator system feeding system

The cartesian manipulator system was composed of four individual suction and gripper devices.

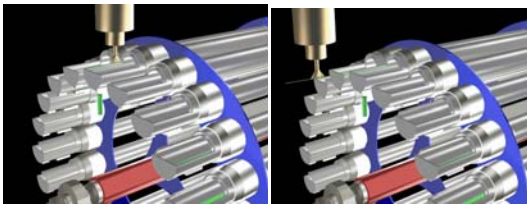

Figure 6 Projected Cartesian manipulator to pick up the fibres.

The function of this individual system is to pick and hold one fibre from the appropriated individual store tube of the drum store and forward it to the input cone of the first fibre advance mechanism (see Figure 7).

Pressure and optical sensors are used to detect the presence of the fibre in the device.

First, a pneumatic cylinder goes down to pick the fibre. At the end of the shaft a hole connected to a vacuum generator tries to capture a fibre. When a fibre is captured the vacuum sensor detects it and the pneumatic cylinder pulls the fibre just the necessary for it to be captured by the gripper.

During operation, if the fibre is not picked up from the tube store at the first trial, the system will make other attempts. After 5 successive failures, the operator will be called.

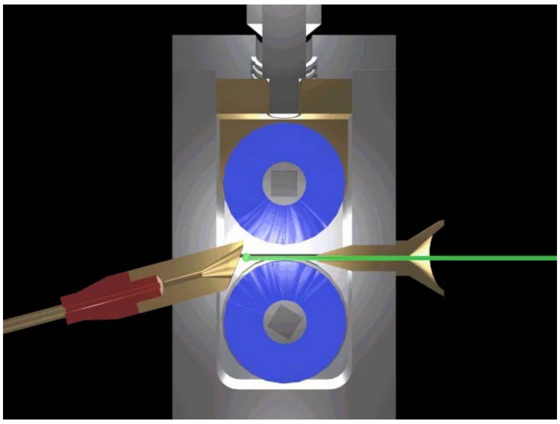

Figure 7: First advance mechanism

Each suction and gripper device works in each fibre independently, allowing simultaneous retrieval of all the fibres. The insertion operation will continue only if all the individual suction devices and respective gripper are able to pick up the fibres from the respective tube store.

2.1.3 First fibre advance mechanism

Near each individual suction/gripper device there is an advance mechanism (Figure 7). Each of these mechanisms is essentially composed of two wheels, which force the fibre to advance towards the insertion table through a special plastic tube (Figure 8). One wheel in powered by an electrical motor with a velocity controller and the other wheel acts as a dummy wheel.
The presence of the fibre at the input and output of this mechanism are monitored with optical sensors.
The control system monitors the advance of the fibre by checking the local insertion time and comparing it with the standard time previously assigned. After that time, if the fibre was not inserted (i.e., the end of the fibre was not detected at the output of the advance mechanism) the system will call the operator.

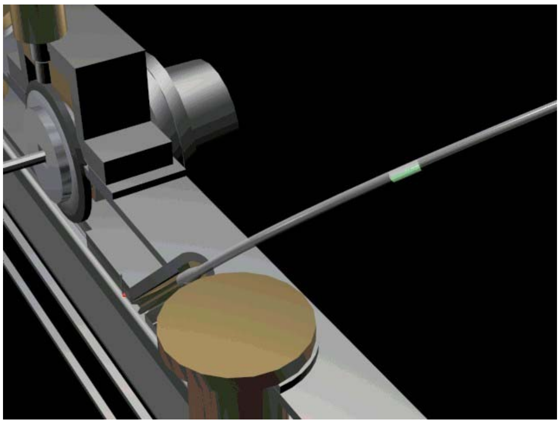

Figure 8: First advance mechanism pushing the fibre into the insertion table, through a plastic tube

All the advance mechanisms are mechanically synchronized to reduce fibre strains.

2.1.4 Insertion table

Inside the insertion table, the profile where the fibres are to be inserted is laid down in a groove. This table is fixed and has a head cap which moves in a cartesian way (see Figure 9). Pneumatic cylinders softly open and close the head cap. When opened the operator is allowed to put a new profile (or retrieve a finished profile). When the insertion starts, the head cap is down (closed) and the profile is in place.

The profile is maintained in position by means of a suction mechanism, avoiding movements during the insertion phase.
The arrival of the fibre to the insertion table is made through the head cap as shown in Figure 10 [Sabino 1997].

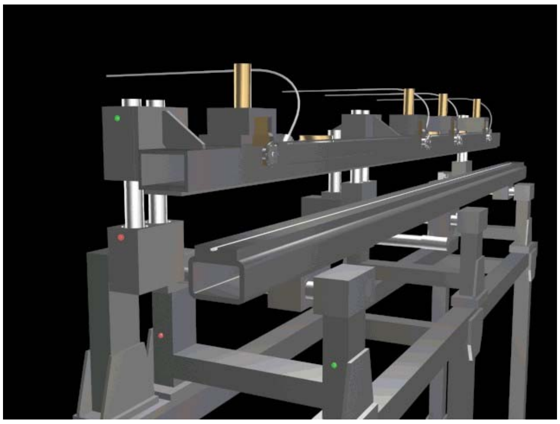

Figure 9: Insertion table with head cap

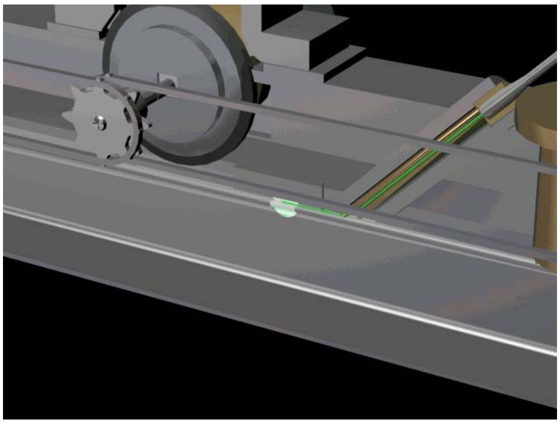

Figure 10: First advance mechanism view when the end of the fibre arrives to the profile.

2.1.5 Head cap of the insertion table

One of the most important and complex mechanical part of the robotized machine is the head cap of the insertion table. This head cap has two degrees of freedom motion, pneumatically actuated, and has six fibres advance mechanisms, six fibre guiding devices, six glue devices, and six position optical sensors.

The fibre is fixed to the profile with a drop of glue, near the aluminised end.

2.1.6 Control system

The overall control system accesses all the information from the sensors and actuators and interacts with the operator. The controller is mainly based in one Personal Computer with analogue and digital interfaces cards (Figure 11). Pneumatic signals are convoyed by digital inputs and outputs. Analog outputs are use to set the speed of the AC motor controllers. The signal conditioning cards and the controllers are placed inside an industrial wall cabinet as shown in Figure 12 [Selma 1999].

The control program was defined in Sequential Function Charts [Dal Maso 1997] (former Grafcet) and implemented in C language [Gonzaga 1998].

Figure 11: Artistic view of the Control System

Figure 12: Real Control System

In normal mode, the control program allows the execution of the all insertion cycle.
In manual mode it allows the execution of each particular operation, independently. This last facility is useful for testing and calibration of the insertion robot.
The controller has fault detection and diagnosis system that allows the operator to be informed when a fault occurs in the robotized insertion machine.

2.2. Test and Calibration

Partial tests have been carried out, in the insertion robot, namely, tests of the suction devices needed to pick the optical fibres from the storage tubes; tests with the gripper which holds the optical fibre and inserts it into the feeding cone; tests with the first motion advance device which feeds the optical fibre into the insertion table; and, tests with the second motion advance device which feeds the optical fibre into the profile.
Several sets of fibres and profiles with different shapes and dimensions have been used for testing and calibration of all parts of the robot, for the insertion of the optical fibres into the profiles. In all the observed failures, the insertion of the fibre into the profile by hand was also impossible, since the internal channels of those profiles were too narrow for a proper insertion [Gouveia 1999].
The tests included the quality control of the optical properties of the WLS fibres before and after insertion into the profiles. A dedicated test bench to measure the optical properties of the fibres was used [Saraiva 2004]. Several fibres have been inserted in order to evaluate eventual damage caused along the full path from the drum to the profile and also eventual damage caused by the roughness of the profile. The light loss in the fibres due to damage when moving inside the path tubes, damage in the insertion into the profiles, damage made to the profiles and damage due to the gluing was smaller than 3% [Gouveia 1999].

2. 4 Operation of the insertion robot

For the machine to work properly, drums should be filled with correct length optical fibres. Figure 13 shows an operator filling the drums with the corresponding fibres.

Figure 13: Operator inserting fibres inside the drum

The entire cycle of insertion of the optical fibres into the profile is made up of several steps, namely:

• The robotized insertion machine is put at rest (home position).
• The operator gives the production plan to the controller.
• The operator gives the fibre storage content to the controller.

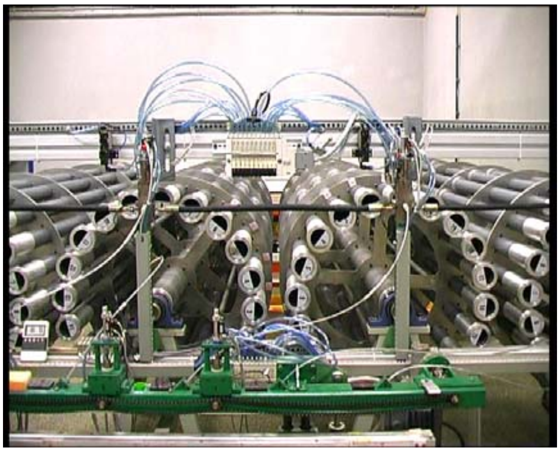

Figure 14: Drums being positioned for the right type of fibres

Normal cycle
• The operator pushes the button of initialisation of the cycle.
• The operator inserts the special profile into the table and instructs the controller when finishes the operation.
• The controller initialises the insertion operation looking to the production plan and fibre storage content.
• The controller gives the order to position the drum stores in the correct position in order to have the correct fibre length in position (Figure 14).

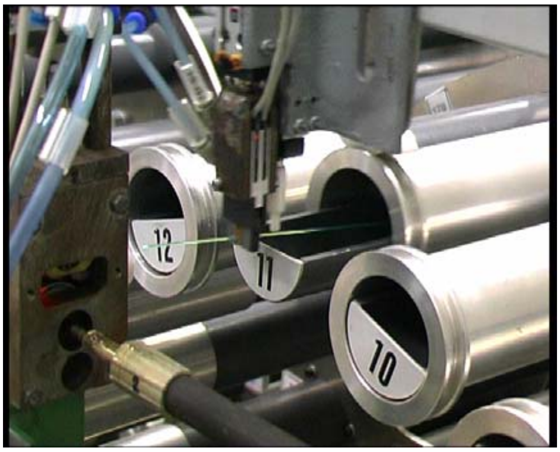

Figure 15: Cartesian robot picking a fibre

• When this operation is done, the cartesian manipulator system for picking fibres (Figure 15, Figure 16) holds the appropriate fibres and inserts them into the first fibre advance mechanism (Figure 17).

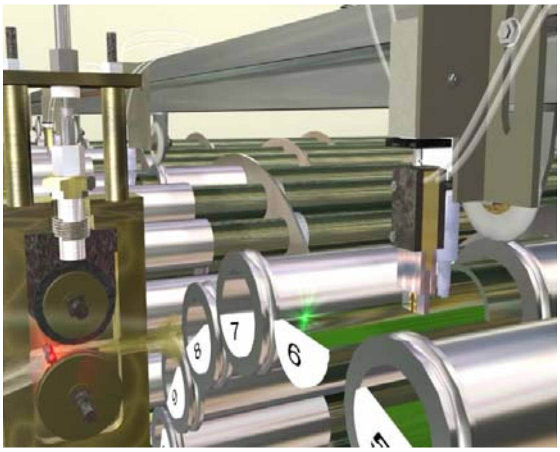

Figure 16: The gripper picking a fibre

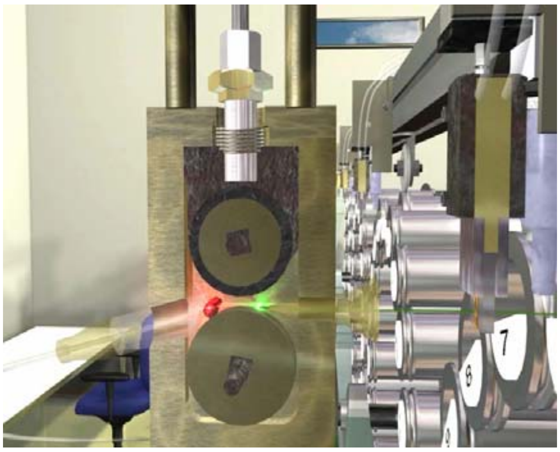

Figure 17: The Robot introducing the fibre in the first fibre advance mechanism

• When the presence of the fibres is detected in the fibre advance mechanisms they will start forwarding the fibres to the insertion table (Figure 18), (Figure 19).

This operation is only done if the table is already closed meaning that the operator has time enough to retrieve the finished profile and put a new one.

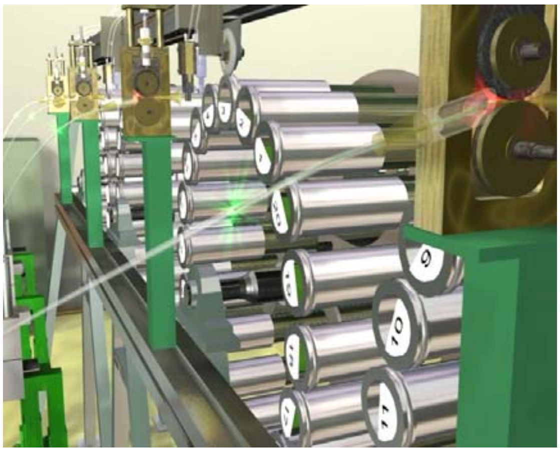

Figure 18: The fibres being guided to the profile (project)

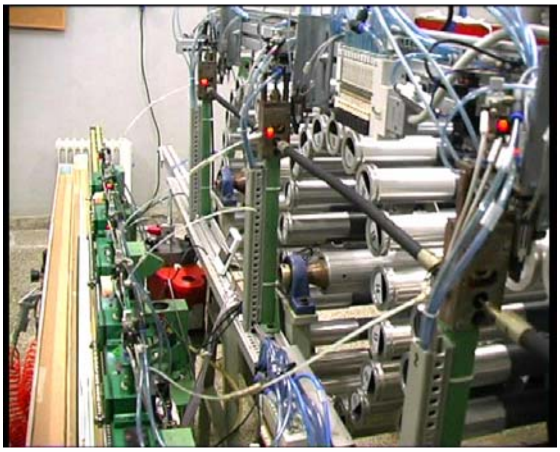

Figure 19: The fibres being guided to the profile (implementation)

- The optical sensors in the head cap of the insertion table will detect the presence of the fibres and the second fibre advance mechanism starts moving the fibre into the profile with the help of the guiding device (Figure 20).

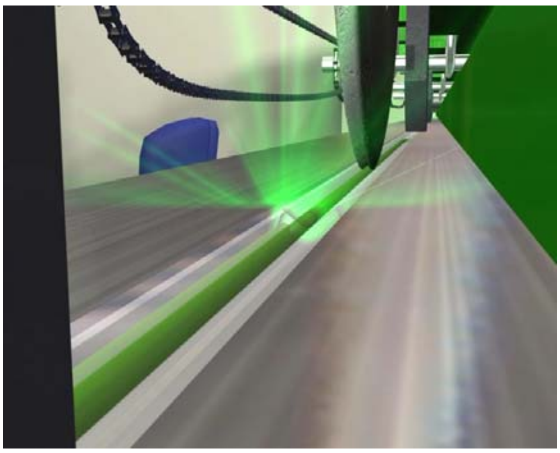

Figure 20: Fibres arriving to the second fibre advance mechanism

The start of the movement is made by actuating pneumatic microcylinders that push the fibre against a moving wheel. The wheel is mechanically synchronized with the other wheels of the advance systems.

- Fibres are guided by the head cap and inserted in the profile holes.

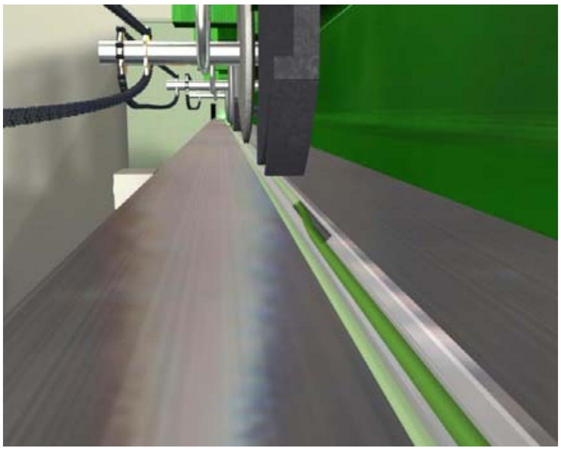

Figure 21: Fibre being guided to the profile hole

- When the optical sensor located near the glue point detects the aluminised end of the fibre, the second advance mechanism stops.
- Being all advanced mechanisms stopped, the control system raises the head cap to let the operator drop the glue in the appropriate point (Figure 22) (Figure 23).

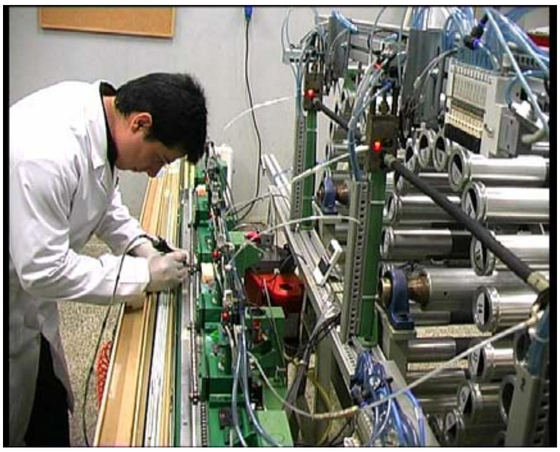

Figure 22: Operator doing the gluing operation

- In the meanwhile, when all the fibres left the first advanced mechanism, the control systems starts positioning the drums for the next set of fibres to be inserted on the next profile.

• The system will wait a few seconds for the glue to dry and frees the profile releasing the vacuum system that keeps the profile in place.
• The operator takes out the finished profile.
• The operator puts another profile and sends an indication to the control system that new profile is in place.
• The system controller closes the head cap and starts another insertion as soon as the drums are in place.

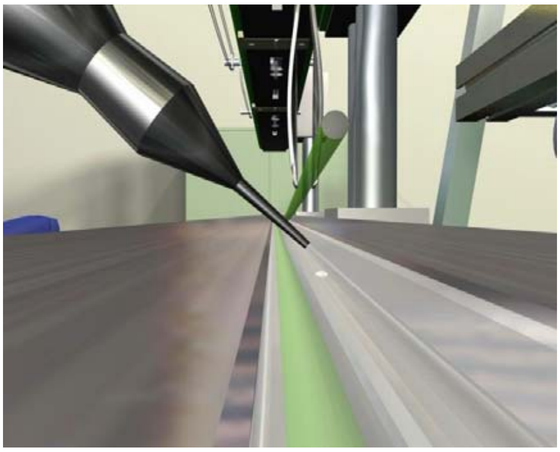

Figure 23: Gluing manual operation

• After, the cycle is repeated again till the production plan is fully done.

3- RESULTS

As shown in the previous figures the system was implemented and accomplished its main goals. A manual introduction of all the fibres into the profiles would take years. The robot was able to perform the introduction of fibres on near 800 profiles/day, reducing to some months the work that would take many years to do.
Initially the idea was to use the suction system both to pick a fibre and pull it towards the first fibre advance mechanism. However, in practice, we noticed that the suction system worked well for picking one fibre among the set of fibres but it was not well suited for pulling it towards the fibre advance mechanism. This was because the length and consequent weight of the fibres in some cases caused the suction system to slide along the fibre and loosing it. The suction system was then combined with a gripper that was much more suitable to pull the fibre. Figure 8 shows the projected system containing just the suction system and Figure 15 shows the implementation already with the gripper. Figure 24 shows the suction system picking a fibre before the gripper catches and pulls the fibre towards the advance mechanism.

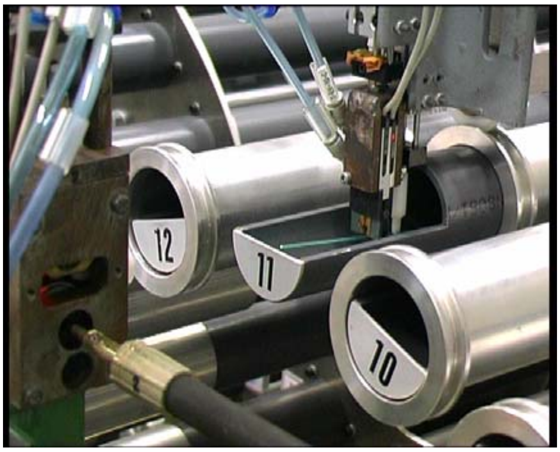

Figure 24: The suction system acting before the gripper

A total of more or less 550000 fibres were introduced into 160.000 profiles by the machine. These profiles were assembled on 195 detector modules.
The percentage of damage fibres was sampled on 94 of the 195 built modules. This percentage varied from 0.12% to 2.2% (0.7% average) for each module.
The insertion process last for three years (6 months IST/Lisbon and 2.5 years at LIP-Coimbra). The insertion rate measured during the insertions corresponding to 8 modules was 230 profiles a day.

4. CONCLUSIONS

We described all the phases of a functional specific robot made to introduce optical fibres into a specific profile. The construction of this robot involved the manipulation of delicate materials, and, as stated before, after an extensive bibliography search no similar work have been report on this matter.
The problems to solve were connected to the process of picking and pulling the fibres, the process of synchronizing the advance systems to keep low efforts to the fibres and, finally, the glue system.
The problem of picking up a fibre from a set of fibres was solved by a combination of the suction system with a gripper.
The process of synchronizing the advance systems to keep low efforts to the fibres was solved by mechanical coupling the traction systems and use pneumatic microcylinders to push (or release) the fibre against the synchronized wheels.
The glue system had a major problem. Due to the very small quantity of glue allowed to use without damaging the fibres, an automate gluing operation was not possible. Moreover, the glue quantity was also dependent on the environment conditions.. By

the end, this operation was kept manual. The rate of the production was not affected by the delay of this operation because the drums positioning was a task than ran in parallel, letting the operator enough time to finish the glue operation.
The robot fulfilled this long task in much less time than manual operation with an average rate of failure of 0.7 %.
A movie of the robot functioning can be found at www.lip.pt/experiments/atlas/robot.htm.

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