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A prototype wiring automate for the twister / tango based endplug of the ATLAS muon drift tubes

Technical Note

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1.0 Introduction

The ATLAS muon detector requires the construction of about 400,000 cylindrical aluminium drift tubes. These tubes have a diameter of 30 mm and range in length from about 800 mm to 6250 mm. The ends of the tubes are closed with endplugs which provide a tight gas seal and which serve as the anchor point for the 50 µm diameter gold-plated tungsten-rhenium wire stretched on the axis of each tube.

The individual drift tubes are glued together in planar triple layers and two of these triple layers, separated by a spacer structure, form a “Monitored Drift Tube” (MDT) chamber. The wire within a MDT chamber has to be centred to better than 20 µm (r.m.s.) in projection.

At the early stage of the MDT project the wire was centred within an individual drift tube by wire locators at the tube ends and one or several locators in between. Within a chamber the tubes were centred with respect to the outer tube diameter at the position of the wire locators. In the new concept the wire is exactly positioned by a centring element in the endplug and it is the outer diameter of the endplug which is used for centring the tubes in the chamber.

Considering the large number of drift tubes to be produced, the cost of each component and the labour cost for the tube assembly is a major concern. In this view the CERN muon group has developed a new endplug based on the so-called “Twister” concept as basic wire centring element. This allows an easy way of wiring the individual drift tubes by an automate with high degree of automation. A stream of air is used to blow and suck the wire through the aluminium tube, the twister in the endplug and finally through the 100 - 150 µm inner diameter wire crimp tube. The wiring can be done by one person only, without manually touching the wire. The additional investment costs for this automate are small, about 10 to 20 kCHF, compared with the possible savings on labour costs. The wiring time for one drift tube ranges from below 3 minutes up to about 4 minutes, depending on the length of the tube and the time for pre-tensioning the wire.

A high degree of automation assures equal quality of the tube assembly with different persons involved over the long production period of several years. If the ATLAS muon community could settle to identical components to be used at all production centres an automation would assure an overall good quality. The basic ideas of such an automate were given in the proposal note: “The Twister Endplug”, ATLAS MUON-NO-237, more detailed information on a common endplug is contained in the note of F. Linde: “MDT Endplug Proposal”.

In this note we report on details of the built and tested wiring automate based on the twister endplug. In the mean time our colleagues of Pavia have modified the twister concept and propose the so-called “Tango”. The described wiring automate is compatible with the tango as basic centring element as well.

The prototype wiring automate was designed and constructed to show the feasibility of an automatic wiring using the twister endplug scheme. Successive wiring steps are therefore initiated by manual switches which allow easily a repetition of a step or a change of the step order. The wiring time is not optimized, it can be reduced further by performing some of the steps parallel in time.

It was not our intention to decide on a specific aluminium tube crimping system (e.g. pressure or electromagnetic crimping), nor to propose our way for tensioning the wire, nor how to push the endplug into the aluminium tube. To gain time and money in setting up this wiring automate we re-used as much as possible components of a prototype wiring automate developed in the early stage of the MDT project in 1995/96, see ATLAS-MUON-NO-139 and 200. This concerns mainly the support structure, many pneumatic pistons and valves, the pressure crimping devices and clamps for fixing the aluminium tube in the automate.

A video tape of the MDT tube assembly with the prototype wiring automate is available at the ATLAS secretariat at CERN.

2.0 Drift tube wiring

2.1 The basic wiring scheme and its test set-up

The step-by-step procedure for the wiring of tubes using twister / tango based endplugs is schematically sketched in Figure 1 on the next page. (This Figure is identical to Figure 1-11 of ATLAS MUON-NO-237.)

In the following we denote the endplug near the wire feeding station as ‘near’ endplug, the one at the opposite tube end as ‘far’ endplug. In this wiring scheme a conical nozzle is placed between endplug and aluminium tube and air pressure and air suction is used to feed the wire first through the aluminium tube into the far endplug inclusive the 100 - 150 µm inner diameter wire crimp tube and subsequently by reversing the operation into the near endplug.

The photo shown in Figure 2 gives an overview of the actual realization.

Visible along the diagonal is the support structure, re-used from the previous set-up, only one third of its length is used. It consists of two U-profiles, with openings mounted against each other. The black box at the right lower corner is the back of a motorized wire unrolling station, followed by the wire feeding station. At the left side of the wire feeding station is sticking out a provisional wire clipping and tensioning arm. The wire is tensioned by gravity. Beneath the black box and the wire feeder is an array of electro-valves visible, used to switch 8 bar of compressed air to the different pneumatic pistons.

One sees axially next to the wire feeding station an empty aluminium tube with a clamp and pressure crimping device at each end. The far gas bottle (argon or nitrogen) supplies the air pressure for feeding and blowing the wire through the tube and the endplugs. Behind it and not visible is a radial compressor which creates at its entrance a few 100 mbar of underpressure used for the wire suction at the endplugs. The gas bottle in the rack at the centre of the displayed system contains compressed air of 200 bar. It is used

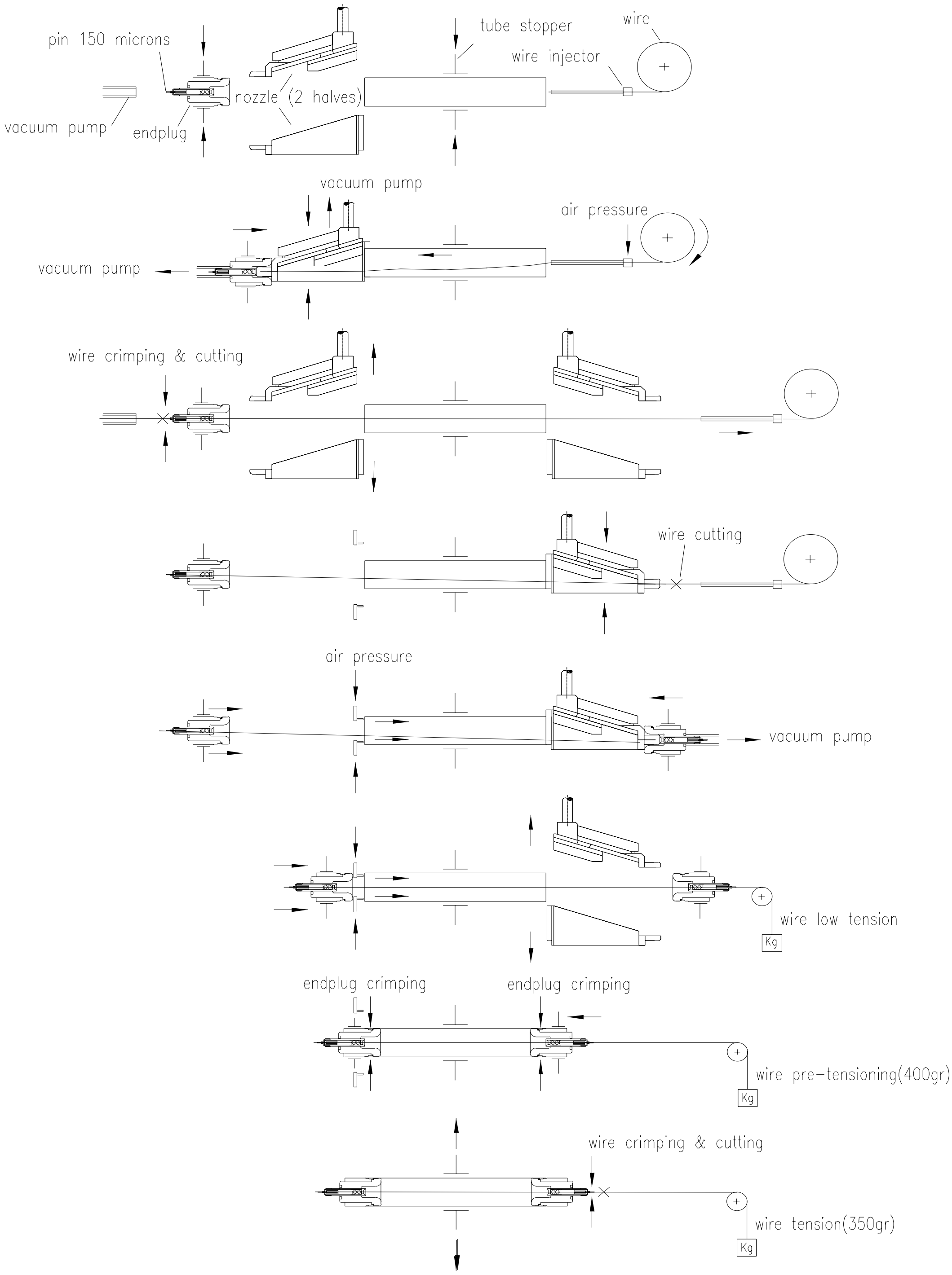

Figure 1: The step-by-step procedure for the wiring of tubes using twister based endplugs

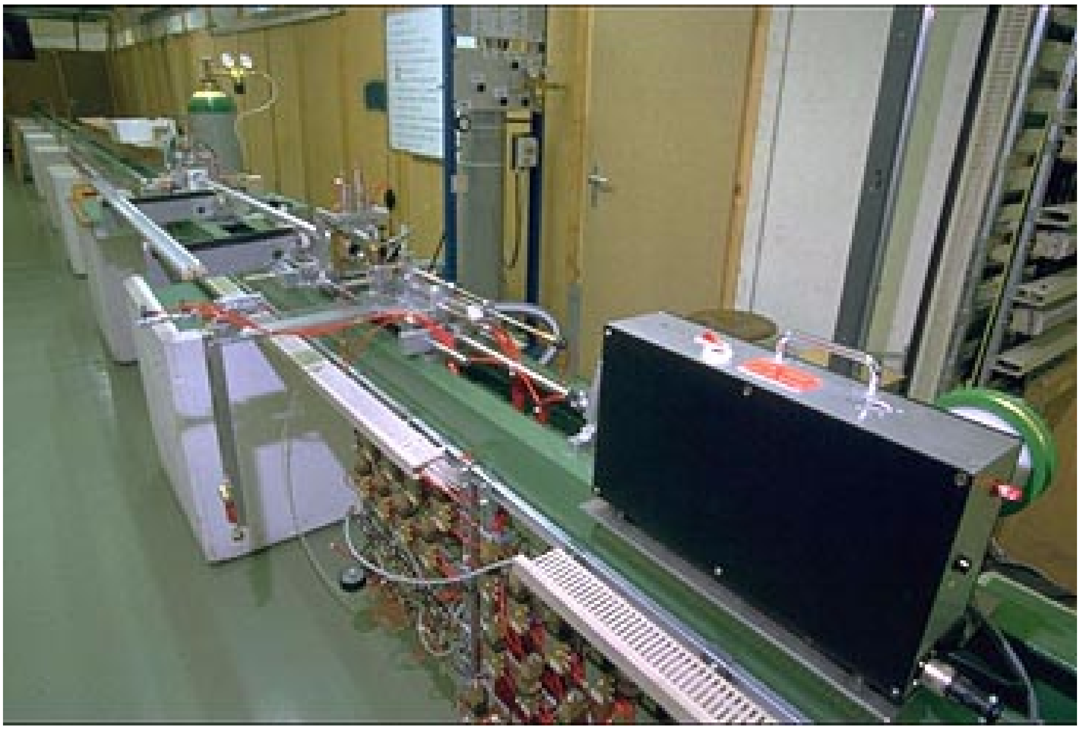

Figure 2: The test stand of the prototype wiring automate

to fix the endplugs in the aluminium tube by pressure crimping. The pressure in this bottle is kept close to 200 bar by a diving compressor.

In the following sections the individual wiring steps displayed in Figure 1 are explained and illustrated by photos for more details.

2.2 Details of the step-by-step wiring

2.2.1 The wire unrolling station

The motorised wire unrolling station (black box), seen on the photo in Figure 3 from its front side, is on loan from another group at CERN. It allows to unroll or to roll back the wire from or onto the spool. The wheel on which the spool is mounted is driven by a motor of little torque. The torque can by varied by a turning knob at the left side of the black box. The turning direction of the motor is such that it permanently tries to roll the wire back onto the spool. The free wire end passes in between two polyurethane covered wheels, which are pressed together and connected to a counter. One of this wheels is motorised. It can turn clock-wise or anticlock-wise and its turning speed can be varied. If it turns forward it will unroll the wire against the torque of the spool motor, if it turns backward the spool motor will roll the wire back onto the spool. The unrolling or rolling back of the wire is by remote controlled hand hold knobs.

The wire unrolling station shown in Figure 3 has a wire cleaning section between the wire spool and the polyurethane covered wheels. It consists of two small containers,

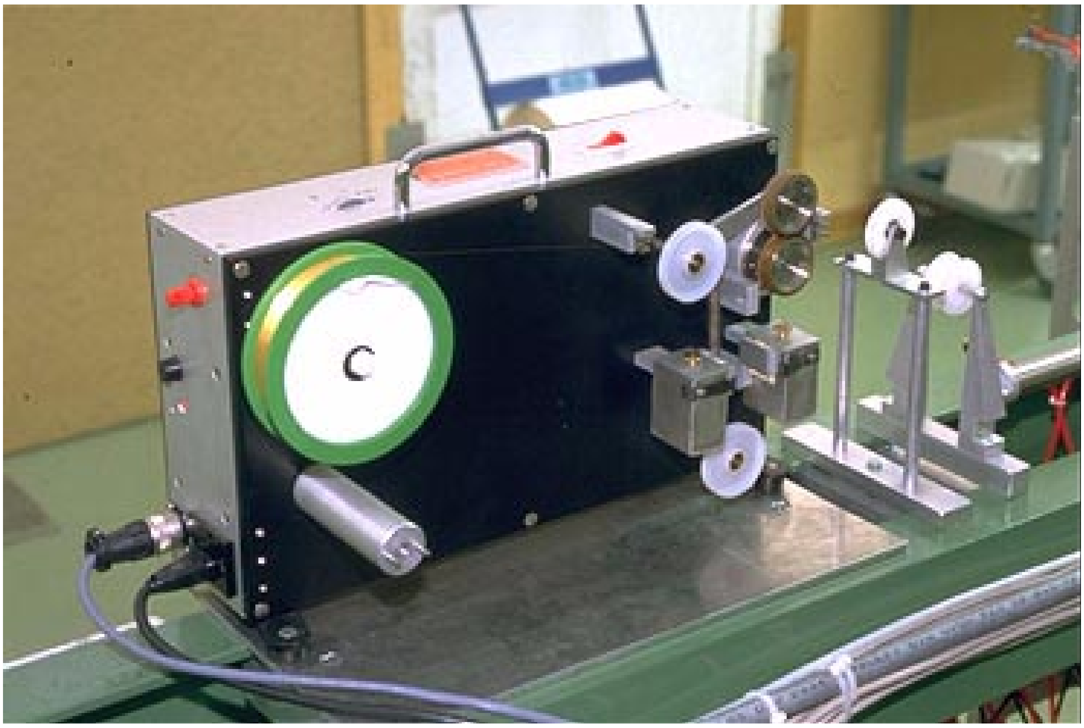

Figure 3: The wire unrolling station used in the test stand

filled with isopropylalcohol, to which a folded felt strip is fixed, with one felt end dipped into the alcohol. The wire is pulled between the folded felt strips.

The wire cleaning didn't seem to be useful, therefore no wire cleaning is considered for the time being. This simplifies the wire unrolling station considerably. Only one motor with variable speed is needed which can turn clock-wise or anticlock-wise, to unroll or roll back the wire. (This is what we actually have installed today.)

2.2.2 The wire injector

The photo on Figure 4 shows the wire injector, positioned between the wire unrolling station and the near tube end; the wire enters from the right.

The wire injector consists of a 40 cm long metallic tube of 3 mm inside diameter to which at the end of the wire unrolling station a short brass tube of larger diameter is screwed on and connected to the argon (or nitrogen) circuit. Into the open end of the brass tube a 10 cm long injection needle of about 1 mm inside and 2 mm outside diameter is screwed in. The outer end of the injection needle itself is closed with a conducting poly-tetra-fluor-ethylene plug (Lubriflon) with a 200 µm hole for the wire passage. Blowing argon (or nitrogen) of a few bar into the large diameter brass tube and unrolling the wire will create enough gas flow to pull the wire out of the injector and blow it through the aluminium tube into the far endplug. The argon pressure for the injection varies between 2 to 6 bar depending on the length of the muon drift tube.

The wire injector, the plexiglass tube as well as their common support can individually be displaced in axial direction by pneumatic pistons, as can by seen in Figure 4.

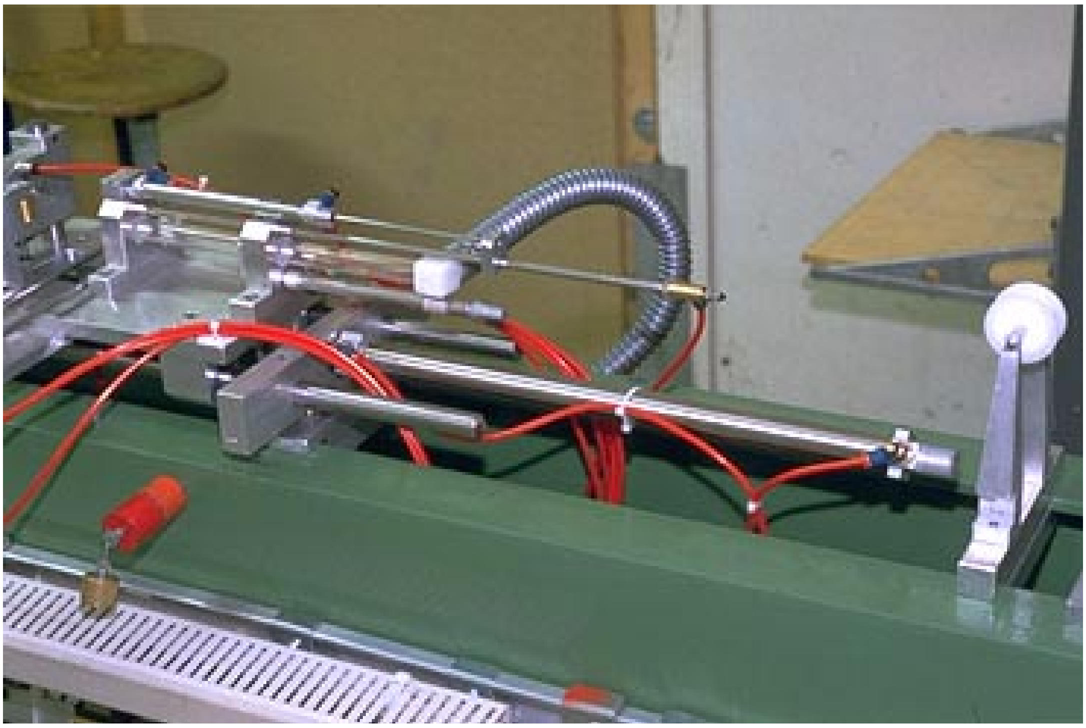

Figure 4: The actual wire injector is the long small diameter metallic tube. The transparent plexiglass tube beneath it is used to suck the wire at the near endplug

The 40 cm long metallic tube as well as the injection needle have very smooth inside surfaces, created by electrochemical deposition of nickel. This assures in addition to the strong air flow, which surrounds the wire, a save passage of the wire without damage.

In earlier tests the 3 mm tube was filled with a slightly conducting nylon tube of 2 mm inside diameter to protect the wire from damage during its passage. Investigations of the wire under a microscope showed occasionally little plastic whiskers at the wire. The nylon coverage was therefore suppressed and replaced by the smooth metallic surfaces, as explained above.

2.2.3 Mounting of the aluminium tube

Near each tube end a pair of pressure crimper/tube clamps are mounted onto a common support plate. Each of the supports can independently be displaced axially by a pneumatic piston. In a first step the supports are axially outwards, allowing to place an empty aluminium tube on rollers in between. The tube is then at its far end manually pushed through the open clamp into the pressure crimper. Its correct axial position is assured by a plastic stopper temporarily introduced into the crimper before clamping the tube pneumatically at this end. Next, the crimper/clamp pairs at each end are pushed by pistons towards each other in the correct axial position, determined by the tube length, and the tube is clamped also at the close end.

The photo in Figure 5 shows the far tube end with the pressure crimper visible, the tube clamp is hidden behind it. On the table on the left is seen the plastic stopper for the tube

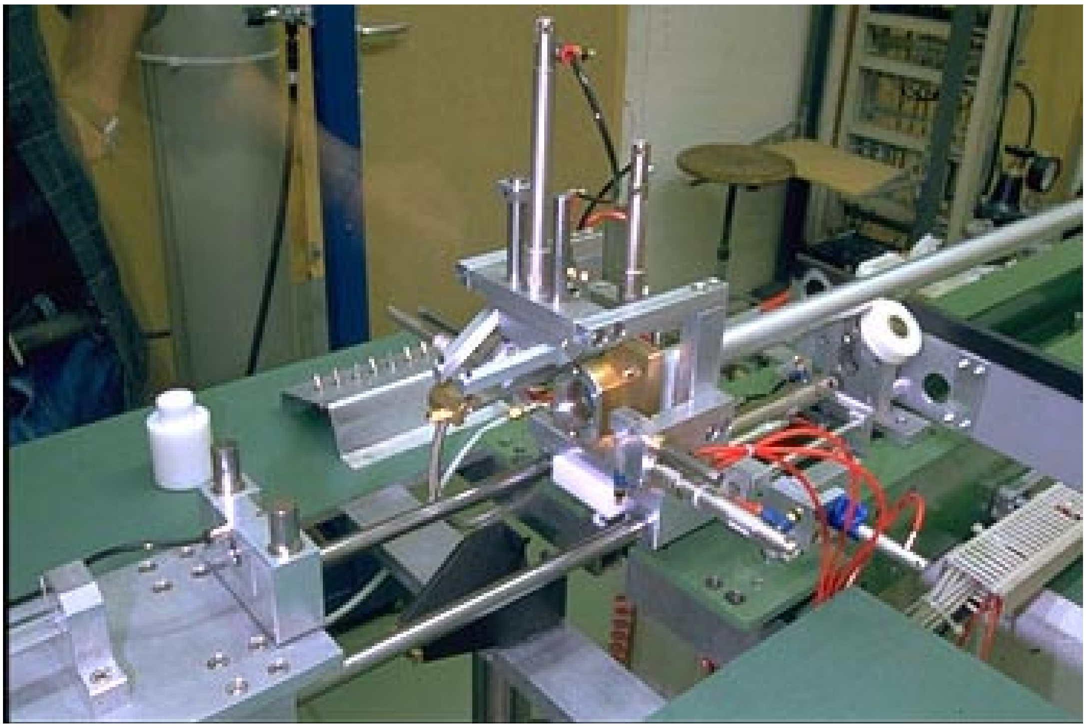

Figure 5: Overview of the arrangement at the far tube end with pressure crimper and manual switches

positioning and an array of manual switches for operating the different pneumatic valves and pistons.

2.2.4 Wiring of the far endplug

To wire the endplug, a conical nozzle, consisting of two halves, is placed between tube crimper and endplug. The two nozzle halves are seen in Figure 6.

The lower one is made of anodised aluminium, the upper one has a plexiglass window for watching the wire when it passes the cone. The black colour of the lower half increases the visibility of the wire. The two nozzle halves are closed and the opening of the tube pressure crimper is pushed onto its end.

The endplug is placed into a pneumatic clamp and pushed over the nose of the conical nozzle, as pictured on the photo in Figure 7.

The clamp to hold the endplug is a preliminary one, developed for these tests. The final clamp has to be designed according to the final endplug version. It has to position the endplug very precisely during the pressure crimping of the aluminium tube. The transparent plexiglass tube at the left in Figure 7 connects the outer end of the endplug to the suction system.

During this preparational work at the far tube end the wire injector is moved from its garage position to the left onto the near tube end. Having finished all this preparation, the argon flow into the injector and the suction pump are switched on and the wire unroller is activated. The wire floats now in the stream of argon through the aluminium tube into

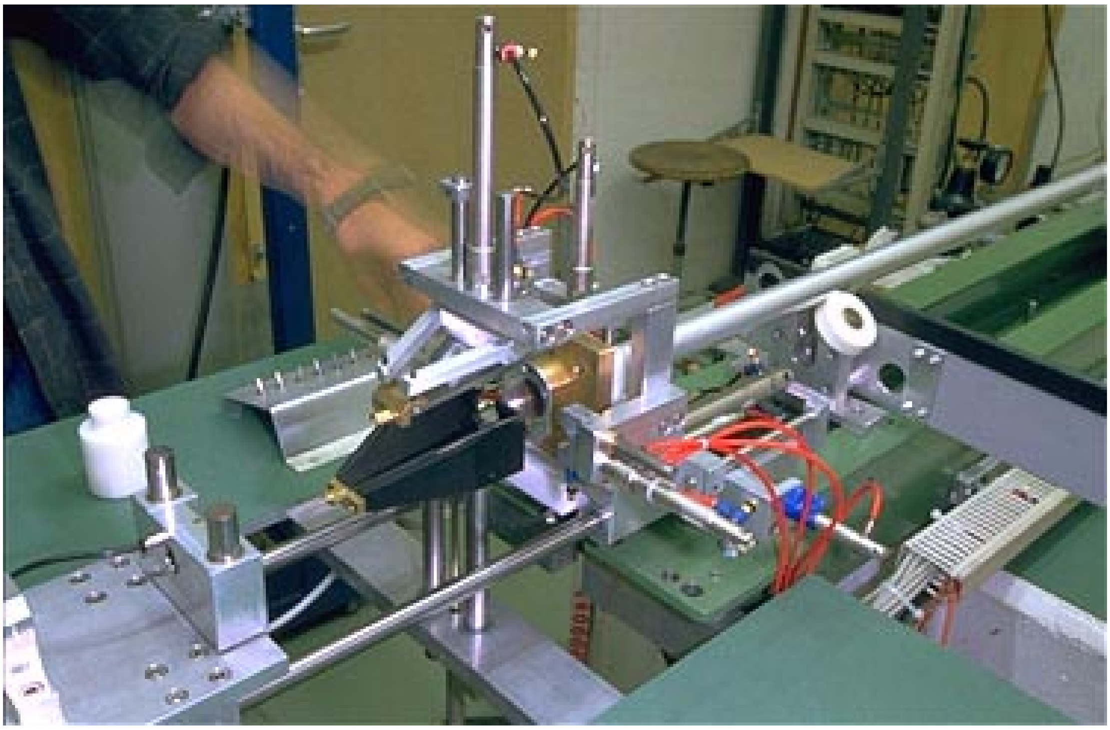

Figure 6: The lower black half of the conical nozzle is put in place, the upper half is going to be lowered

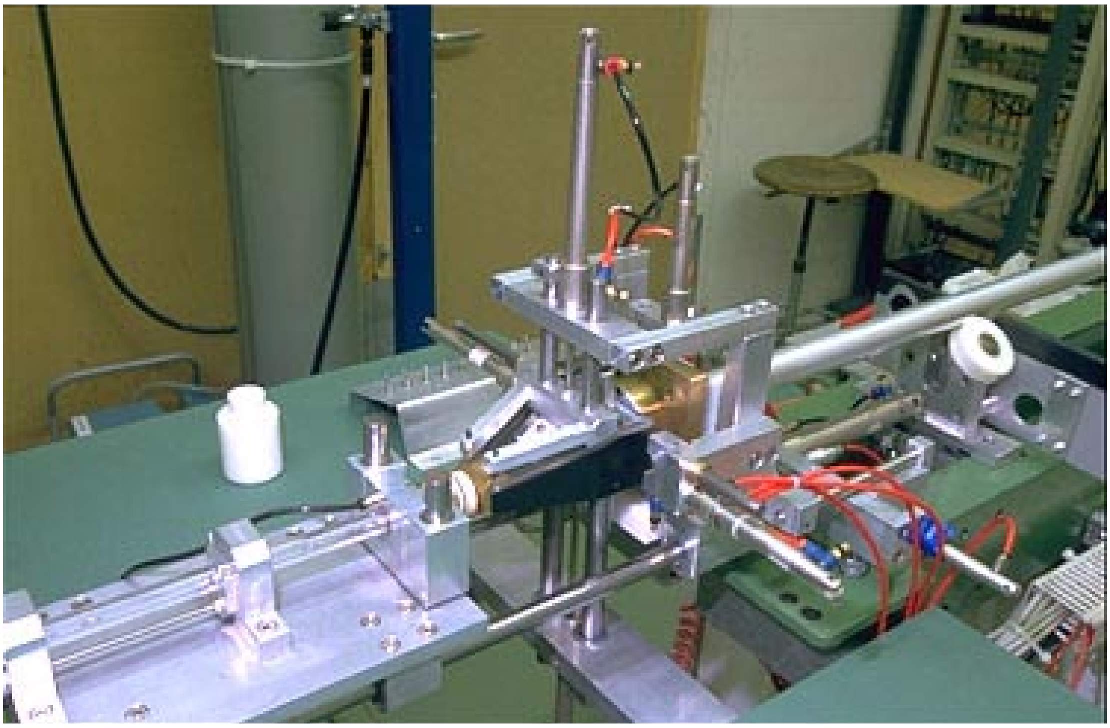

Figure 7: The far endplug ready for wiring

the conical nozzle, from where it is guided into the entrance of the twister and finally finds its way into the 150 μm wire crimp tube.

As soon as the wire passes the crimp tube the wire unroller is stopped, the transparent plexiglass sucking tube is pulled back axially and the wire is crimped with a special pair of pneumatic pliers. Figure 8 shows the wire crimping and the outsticking wire end. The outsticking wire end is cut.

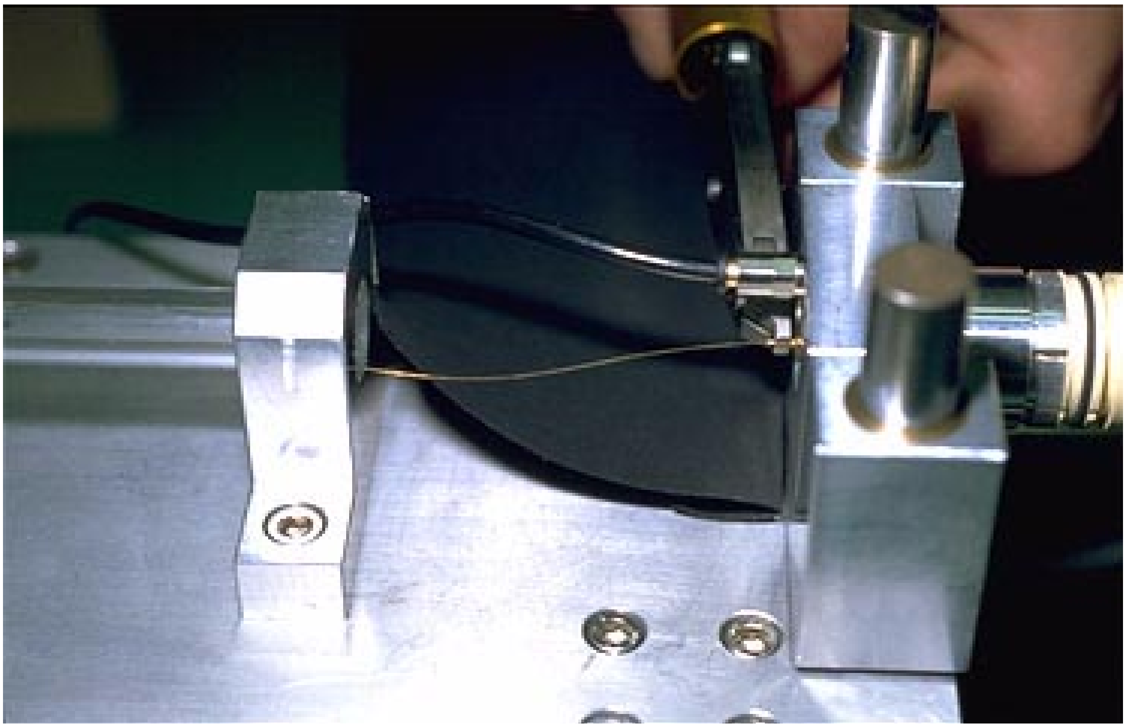

Figure 8: The free wire end sticking out of the wire crimp tube

The far endplug and with it the wire are now pulled a few centimetres away from the conical nozzle, as shown in the photo of Figure 9.

The pressure crimper/clamp pair and with it the aluminium tube is pulled a few millimetre into the other direction. This allows to open the nozzle and to push an argon (or nitrogen) injector onto the far tube end, allowing to blow argon through the aluminium tube in the opposite direction as before, see Figure 10.

2.2.5 Wiring of the near endplug

In the mean time the wire injector at the near tube end was moved far enough away from the tube end allowing to close the two halves of the conical nozzle there, as shown in Figure 11.

Now the wire is cut close to the nozzle as shown in Figure 12 and the free wire end is rolled back into the wire injector.

An endplug is placed into the pneumatic clamp and pushed over the nose of the nozzle, and the transparent plexiglass tube for wire suction is pressed against the endplug, as shown in the photo of Figure 13.

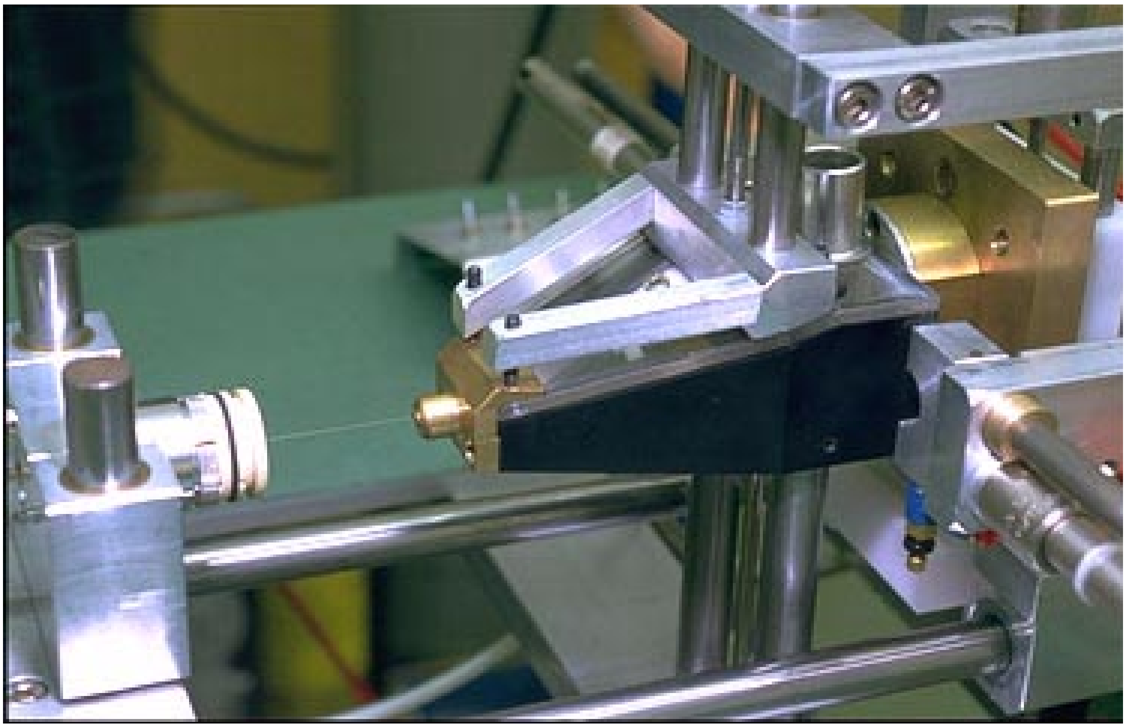

Figure 9: After the wire crimping the endplug is disengaged from the conical nozzle

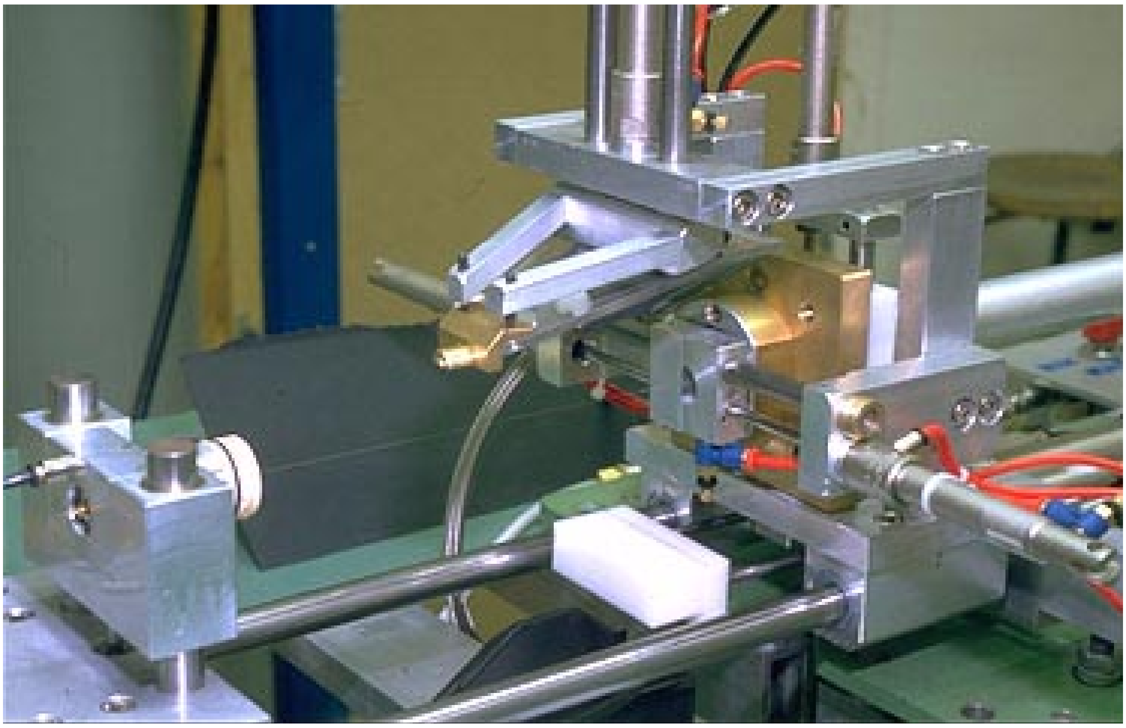

Figure 10: The endplug is pulled further back and the far air injector is placed into position

The suction at the near endplug is switched on and argon is blown from the far injector through the tube. At the same time the far endplug moves towards the tube end, as seen

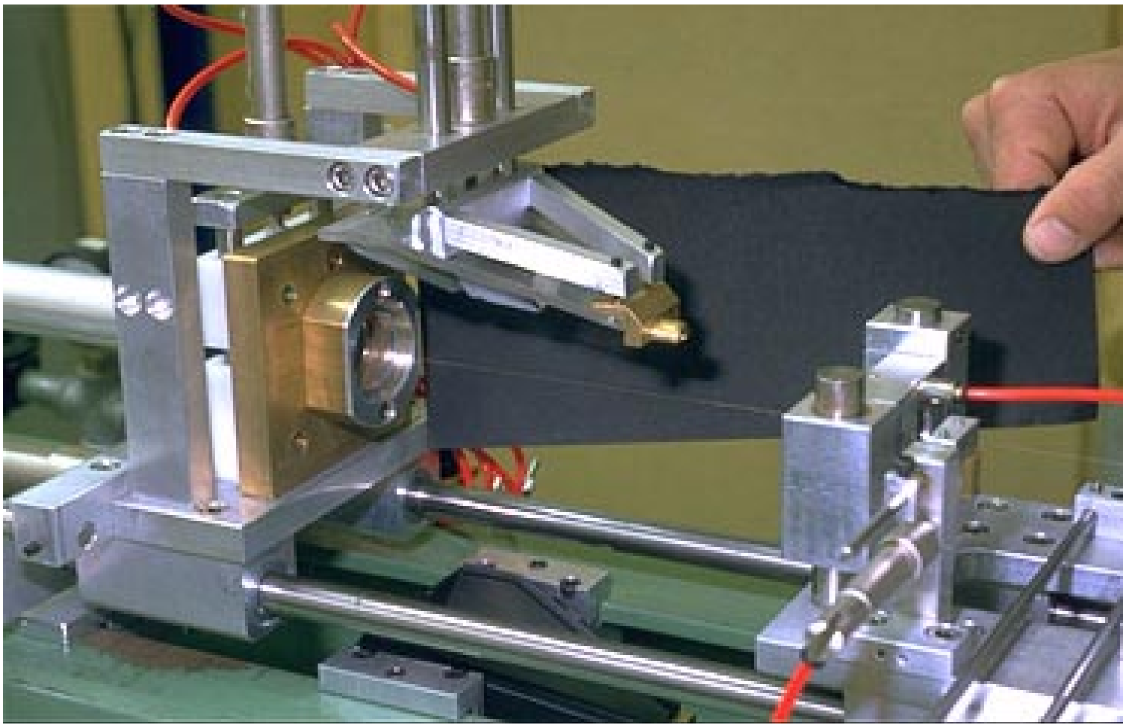

Figure 11: Overview of the conical nozzle arrangement at the near tube end

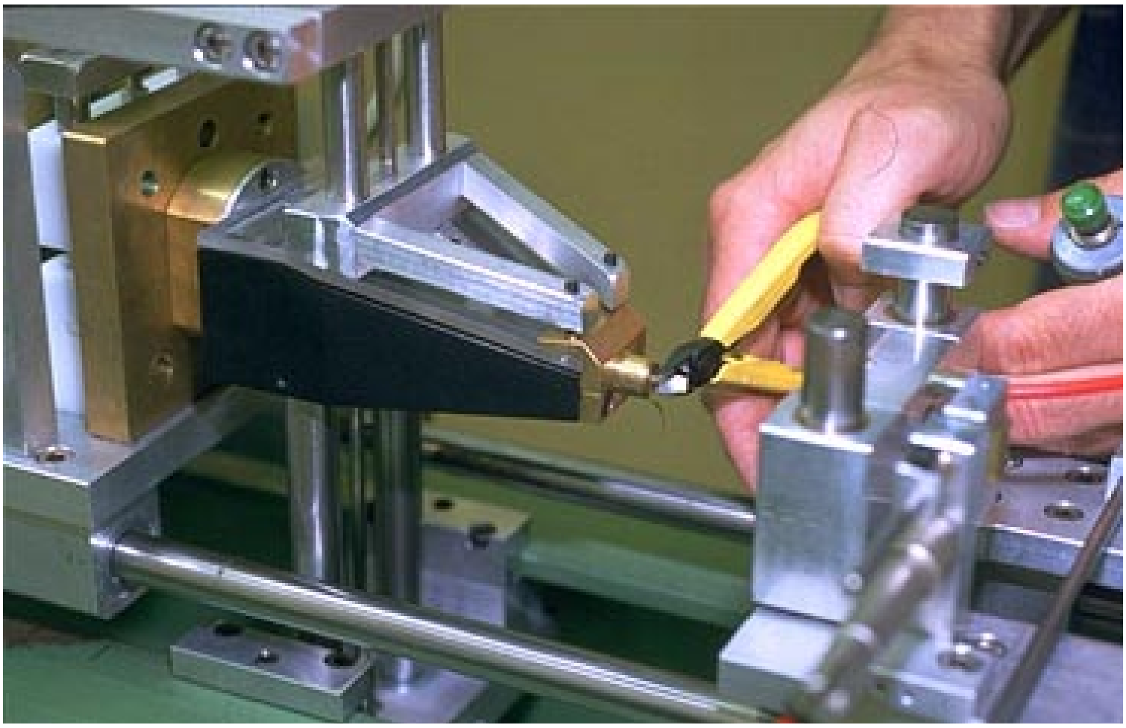

Figure 12: The conical nozzle at the near tube end is placed into position and the outsticking wire is cut to allow rolling its free end back into the wire injector

in the photo shown in Figure 14, and with it advances the wire in the tube allowing in this way to blow and suck the wire through the near endplug and its wire crimp tube.

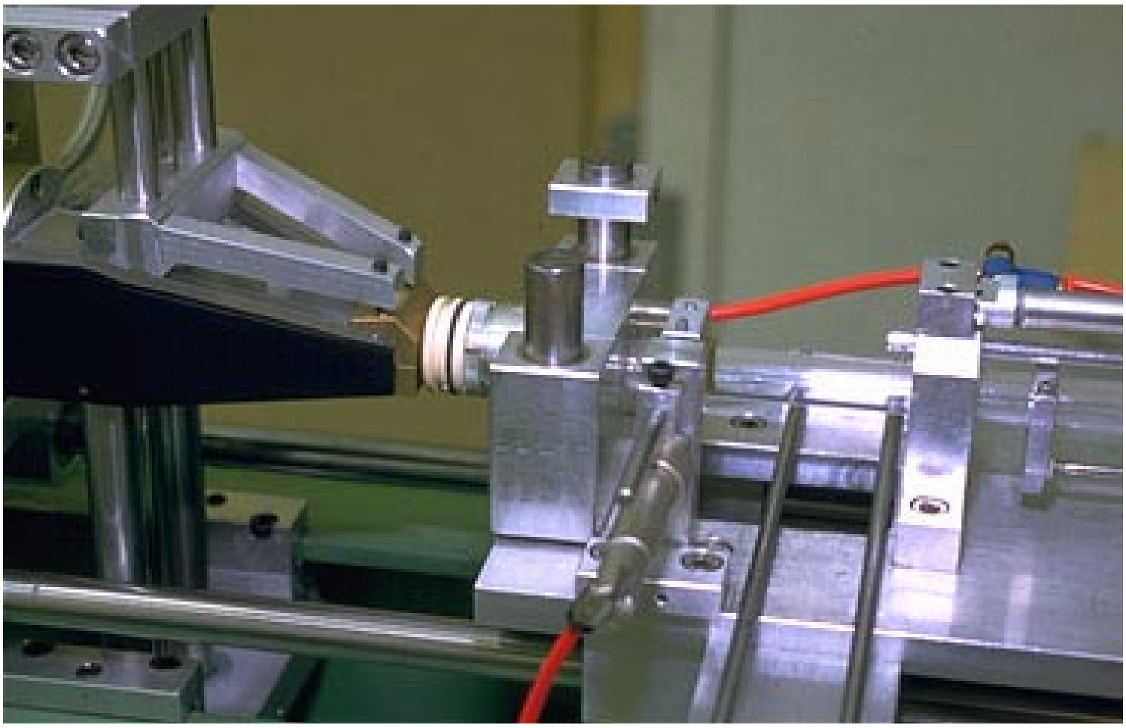

Figure 13: The near endplug is pushed over the nose of the nozzle and the plexiglass suction tube is put in place

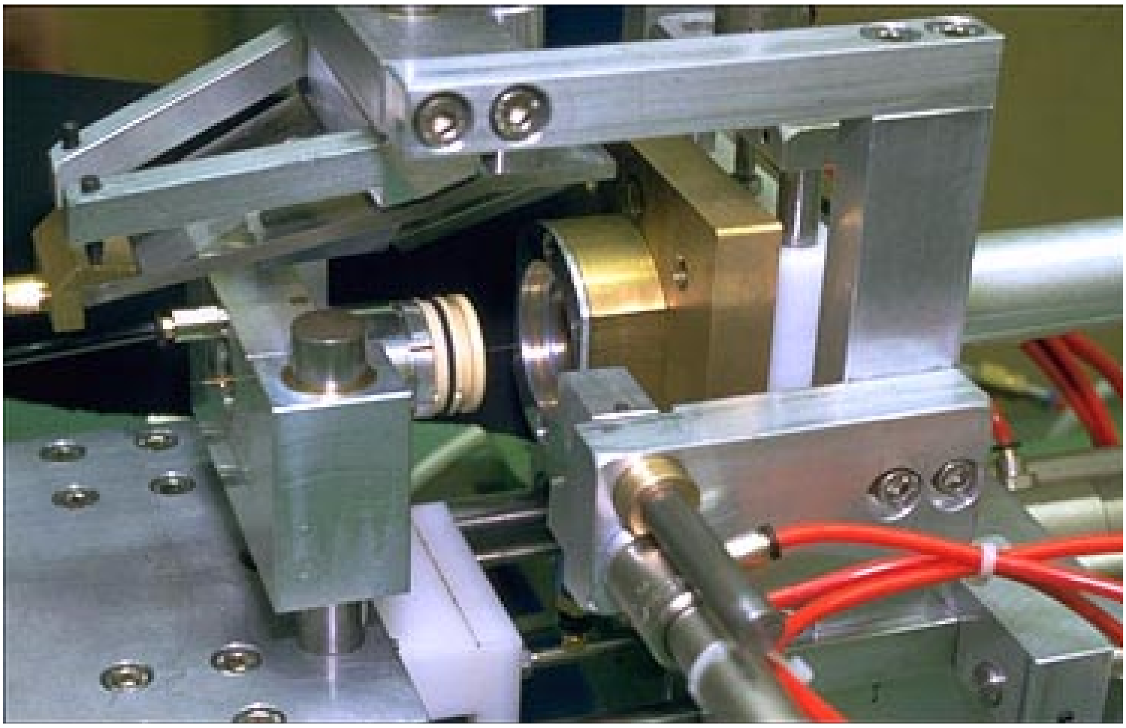

Figure 14: To thread the wire through the near endplug, the far endplug and with it the wire has to advance towards the far tube end

Similar to the procedure followed at the far tube end, the near endplug is slightly pulled back to permit the opening of the conical nozzle halves. Now the transparent plexiglass suction tube is pulled axially some distance away with the free wire end still floating in the airstream in the tube. The wire tensioning head is then moved manually into this free space and the wire is clamped pneumatically between two rough surfaces. The photo in Figure 15 shows this situation.

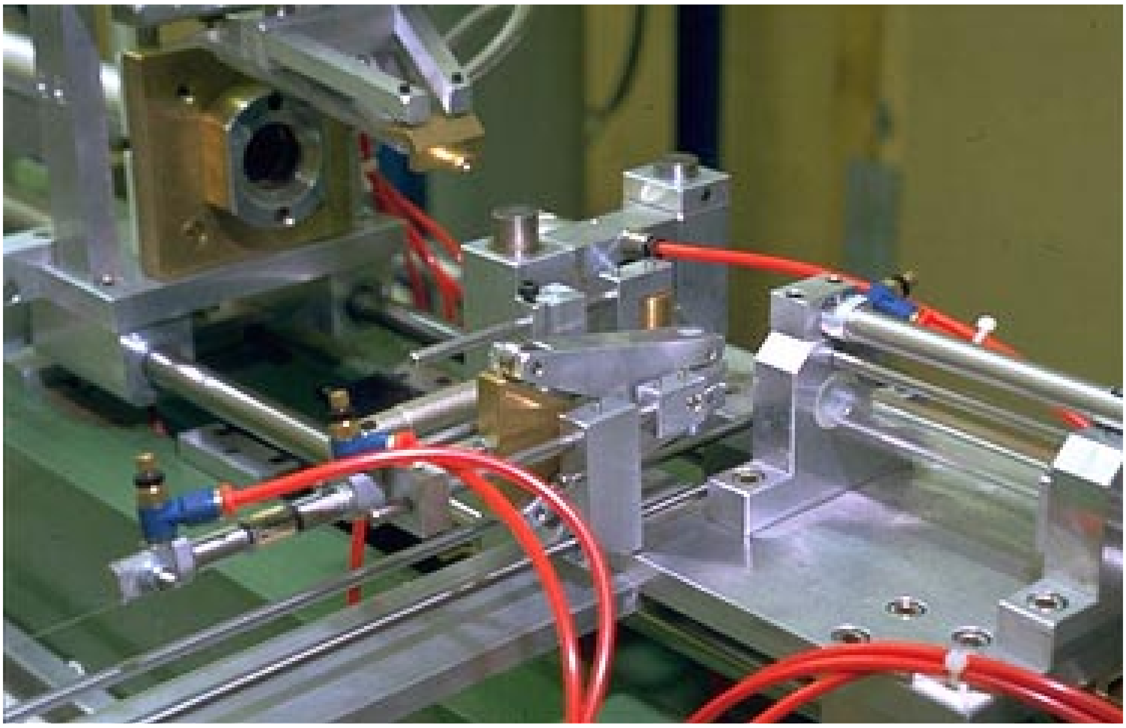

Figure 15: The two jaws of the wire tensioning head pick up the wire and clamp it pneumatically

In this provisional tensioning set-up the wire is pulled sideways over a pulley, which was moved just behind the wire crimp tube. It assures the wire tensioning near the endplug in axial direction. The force with which the clamping head is pulled is given by a weight; the pre-tensioning is done by adding another weight for a certain time. The photo in Figure 16 shows a closer look to the pulley and the wire pulling head.

Now the far endplug is moved into its final position in the aluminium tube and pressure crimped, as shown in Figure 17.

The same is done with the near endplug. The wire tensioning station follows the movement of the endplugs. During this movement the wire is pulled over the pulley and kept under constant tension by the gravity force of the weight. Finally the wire is crimped at the near endplug with the special pair of pneumatic pliers and the free wire end is cut. Figure 18 shows the crimping of the wire at the near endplug.

2.2.6 Finishing the wiring cycle

Now the endplug clamps at each tube end and the pair of pressure crimper/tube clamps are pulled axially outwards into their starting position, allowing to take the finished drift

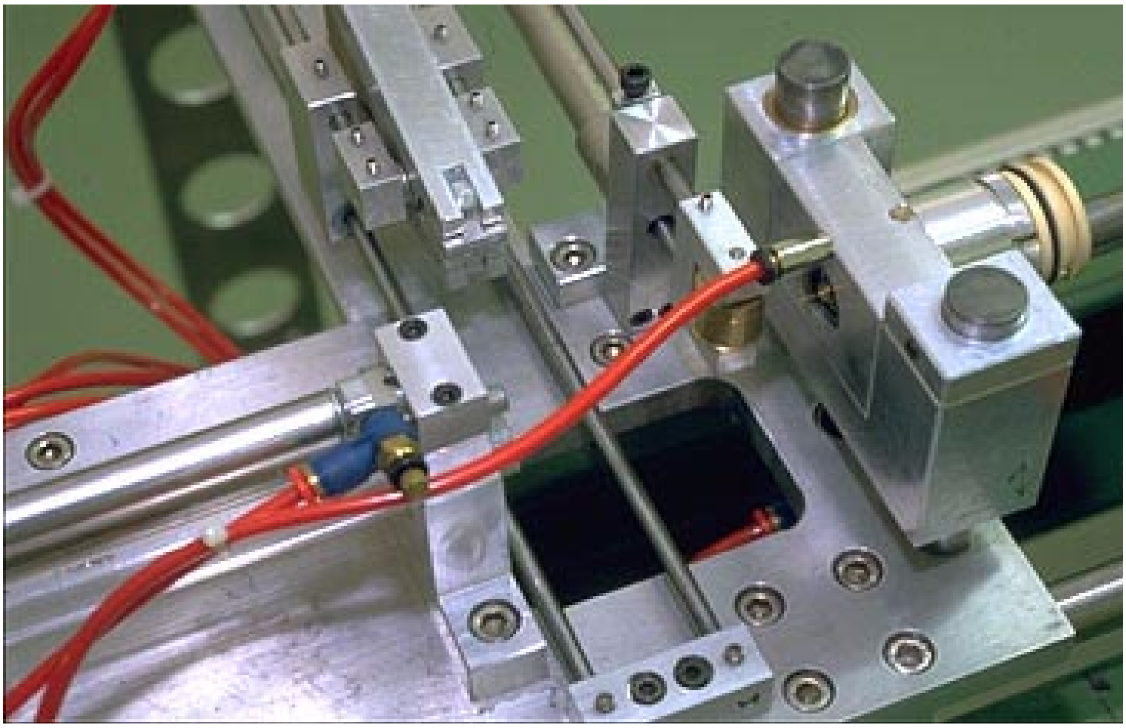

Figure 16: Detailed view at the near endplug arrangement during the wire tensioning situation

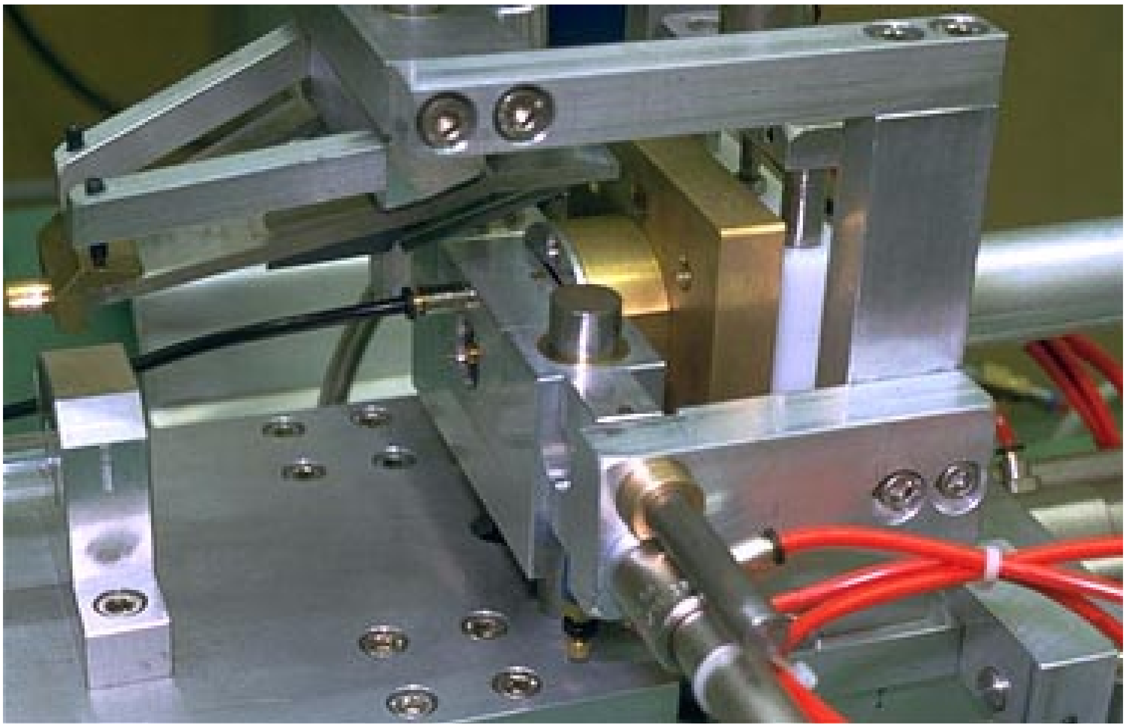

Figure 17: The far endplug is pushed into its final position to be pressure crimped in the aluminium tube

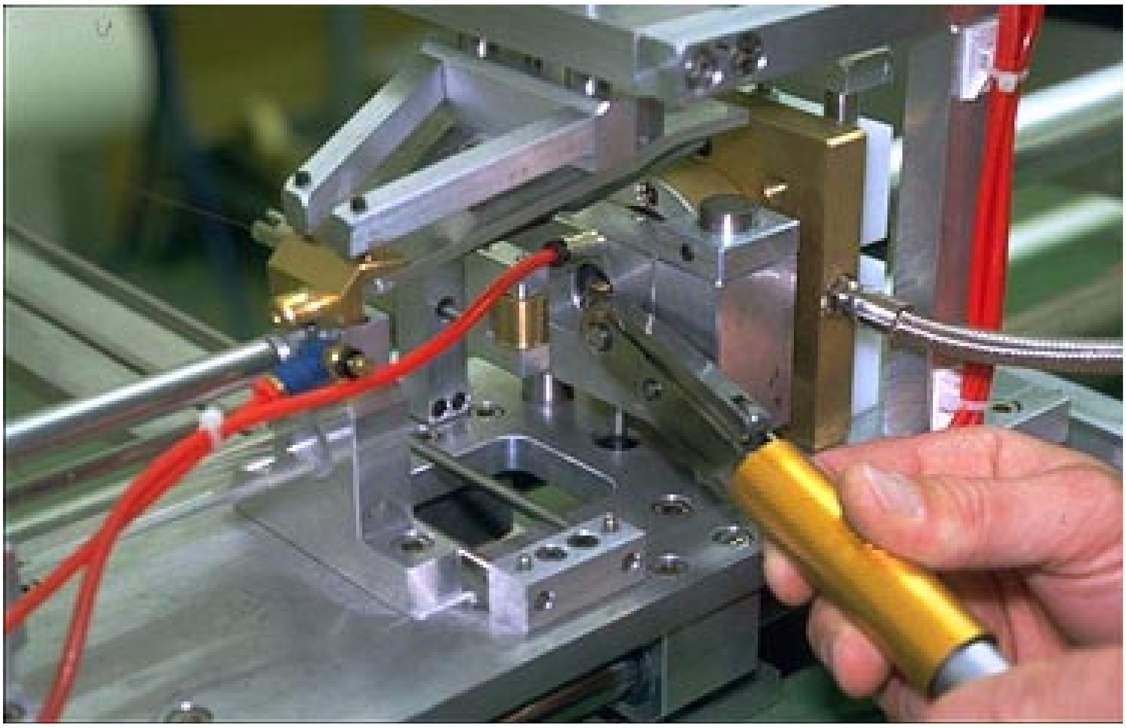

Figure 18: With the near endplug pressure crimped into the aluminium tube, the wire is tensioned to its final value and crimped

tube out and to accept a new empty tube. Figure 19 shows this situation for the near tube end. The black plastic guiding ring at the near tube clamp assures the save introduction of the aluminium tube into the pressure crimper avoiding scratches.

2.2.7 The pneumatic pair of pliers to crimp the wire

The photo in Figure 20 shows the pneumatic pair of pliers for the wire crimping, used at this test set-up. It is optimized for OFHC (oxygene-free-high-conductivity) copper crimp tubes of 0.7 mm outer and of 100 to 200 µm inner diameter. The pneumatic pair of pliers was in this form developed by L. Dumps of the CERN ATLAS TRT group and given on loan to us for the muon drift tube development. The original manual pair of pliers for the above mentioned crimp tubes was developed at CERN by the EF-TA group and finalised by E. Rosso & collaborators of the PPE-TA2 group. It was used in the production of wire chambers for several experiments at the ISR (R608 and R807), in UA1 and at LEAR in the Cristal Barrel detector.

If other crimp tube diameters are to be used a careful study of the dimensions and of the crimping tools have to be done.

3.0 Towards a final wiring automate

The wiring automate, shown in the video film and described in more detail in this paper and its figures, was developed to study and demonstrate its feasibility and to show its usefulness to interested tube production institutes. It is related to the twister / tango

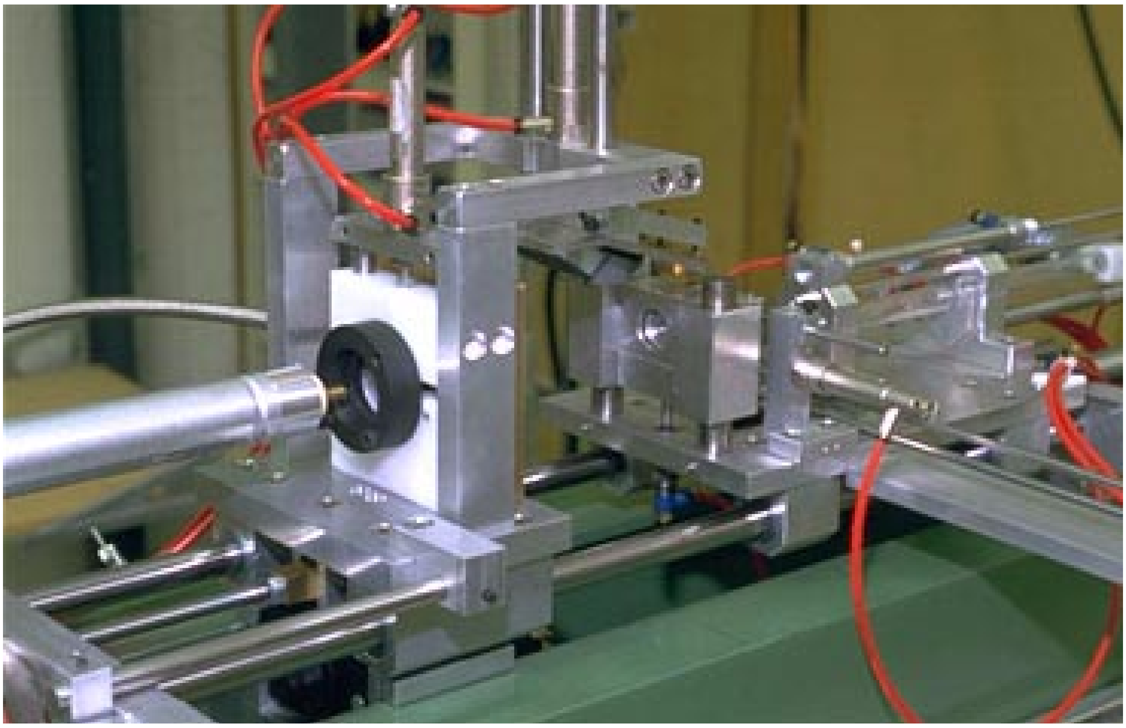

Figure 19: The pressure crimper and the tube clamp at the near tube end at the end of a wiring cycle. The black plastic ring serves to guide the aluminium tube

Figure 20: The pneumatic pair of pliers to crimp the wire, developed at CERN

concept. Some of the original produced wiring elements, e.g the conical nozzles, the wire injector, underwent some modifications to arrive at a proper performance. They will still be improved further in view of an optimization of their functioning and tested out before being proposed for a final wiring automate. The present equipment in the test stand might therefore be slightly different from the one shown on the video film and in this paper.

Some other devices, e.g. the wire tensioning and endplug holders, which we considered as not important for demonstrating the feasibility of an automatic wiring and which were produced provisionally, might be taken over for a final wiring automate with only small modification and adapted to the existing equipment of the institute.

As mentioned in the Introduction only pneumatic pistons were used for the movement of the different wiring components, this because they were already available in the group and used before. Some of the movements, e.g. the displacement of the endplugs, could be done more smoothly and precisely by using a step motor. The arrival of the wire in the plexiglass suction tube after its passage through the far endplug could be measured by an optical sensor or resistive equipment and its signal could then be used to stop the wire unrolling. A LED could be built into the plexiglass cover of the upper nozzle half for better observation of the wire during its passage.

E. Rosso and collaborators at CERN have done extensive studies to develop reliable wire crimp tubes. They found best results with OFHC copper crimp tubes of 120/140 HV 0.3 hardness with outer diameter of 0.7 mm and inner diameter of 100 - 200 µm for wire diameters ranging from 30 - 150 µm. Squeezing such a crimp tube over a length of 3 mm to a thickness of 0.45 mm assures a good flow of copper all around the wire. Few 100,000 wires were safely crimped under these conditions for different experiments without creating long-time problems.

As mentioned in section 2.2.7 a careful study has to be done for new pairs of crimp pliers if a crimp tube other than 0.7 mm outer diameter will be used.

Important for a smooth functioning of the wiring automate are properly deburred crimp tubes and a good quality wire. The wire has to be straight when freely hanging down; a curling wire has to be rejected. This condition has to be clearly stated in the specifications for the wire procurement.

In this prototype wiring automate each different wiring step is initiated by a manual switch, some of the switches are visible in Figure 7. This allows to control the correct functioning of each individual step or to repeat a step if needed. This procedure was absolutely necessary during the development phase when many components had to be invented and to be modified to improve their performance, e.g. the conical nozzles, badly deburred crimp tubes, or were changing for other reasons, e.g. endplugs. Having arrived now to final wiring components and endplugs with a proper QA of them, many of the wiring steps could be chained together to assure a certain automatic wiring flow. Nevertheless a manual high priority interruption of the automatic wiring cycle should always be possible to repeat or to continue manually some of the wiring steps.

Bellisario Esposito and his colleagues from Frascati[1] have taken up with great enthusiasm the task to build, in collaboration with the CERN group, the final wiring automate. The first “final” automate is expected to be ready early in 1999.

4.0 Acknowledgement

First tests in using the twister principle for the wiring of the muon drift tubes were made with in house machined plastic twisters. These twisters were produced on a small special milling machine, developed by S. Triquet (CERN / EST) and kindly lent to us.

We thank our colleagues from Frascati, Pavia and Protvino for providing us with endplugs and crimp tubes for testing the twister / tango principle in this test stand. Our colleagues from NIKHEF produced brass twisters at their institute, our colleagues from Pavia supplied us in addition with industrially produced tangos.

E. Rosso and E. Gaumann from CERN kindly provided us with the wire unrolling station and with wire crimp tubes of 0.7 mm outer diameter. L. Dumps from the CERN ATLAS TRT group we owe thanks for the loan of the pneumatic pair of pliers for the wire crimping.

We thank Jörg Wotschack for originally initiating an automated drift tube wiring and Christian Fabjan for the continuous support of our efforts.

[1] This same group was also involved in our previous work on automated drift tube production (Muon Notes 139 and 200). They developed and provided the first version of endplugs and most of the pressure crimping equipment for the aluminium tubes.