



Improvements/Experience derived from wiring 10% of BIS MDT's

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Abstract

This note describes the improvements performed on the University of Athens Muon Drift Tube assembly line. All implemented QA/QC tests are described. Experience and results of the performance are extracted from the assembly of more than 10% of the BIS tubes.

1 Introduction

University of Athens (UoA) is responsible for the wiring of about 30,000 MDT tubes, to be used for building the BIS chambers. These tubes are ATLAS muon monitored drift tubes of finished length of 1671.5 mm. In a previous note (**ref 1**) we have described the University of Athens wiring line and the wiring procedure used for wiring the BIS module 0 prototype.

Since then, we have performed a series of improvements, implemented new quality checking procedures and have finished wiring more than 10% of the total production. In this note we would like to share our experiences with the rest of the collaboration.

Section 2 describes all the necessary improvements and steps for the tube wiring preparation. In section 3 a brief description of the improvements of the wiring line is given. In section 4 we describe all improvements in the QA/QC procedure. Section 5 describes our DAQ program, while in section 6 we discuss the recovery of tubes with high dark current. Finally, section 7 summarizes our experience and results for the produced tubes.

2 Tube and end-plug preparation for wiring

2.1 End-plug checking and assembly

During construction of module 1, 20% of the tubes were found to be off tolerances, when mounted on the jigs. The height of each of the 40 tubes, mounted on the jigs in order to form a chamber layer, had to be within $\pm 10 \mu\text{m}$. The tubes which were off the above tolerances, despite of not touching with each other, had to be replaced. Most of the problem was finally traced to be due to too large end-plugs. A fraction of the NIEF pre-series end-plugs and some MPI ones had a diameter of the precision surface which was more than the upper limit of the specifications, namely $>30.010+0.010 \text{ mm}$.

Since then, we decided to check EACH end-plug before assembling it and mounting it to the tube. The end-plugs are measured with a go/no-go gauge (**Photo 1**) and verified, from time to time, using a precision ($1\mu\text{m}$) micrometer mounted on the same construction. Most of the new NIEF series end-plugs were found to be OK, but twice we found batches, which contained 20% of the end-plugs outside tolerances (too big once and too small the other time).

After passing the external diameter check, the end-plugs together with the twistors and crimp pins were cleaned in an ultra sonic bath using 100% ethyl alcohol for about 10 min. After insertion of the twister and stopper, the crimp pin had to be crimped on the brass sleeve of the end-plug. One should note that this crimping should be made very tight since a movement of about $10 \mu\text{m}$ of the crimp pin is enough for the tube to fail the wire tension QA test. After a lot of trials, together with a local company (IMMG¹) we developed a crimper (**Photo 2**) based on a precision

¹ Institute of Mechanics of Materials and Geostuctures S.A., Penteli, Greece

choke of a drilling machine. This crimper, using a single movement of the handle shown on the photo, crimps the pin into the sleeve deforming the sleeve in three diametrically equidistant points.

The company has later built a second copy of this crimping device for Beijing University. No tubes crimped with the above crimper failed the wire tension test because of pin movement.

2.2 Tube measurements prior to assembly

The tube wall thickness was sample (5% of the tubes) measured, using a precision micrometer, at eight equidistant points on the tube diameter. All tubes measured so far, were found within tolerances. Quite a few tubes (1.5 %), however, failed the visual inspection prior to wiring. Most of them had scratches in the internal surface. Occasionally, tubes with dents were also found.

3 Improvements in the wiring line

As described in ref 1, our wiring table is an aluminium bench of 50 cm wide and 2.5 m long. On the bench, the various tooling for wiring/quality checking are installed in five different stations/positions which perform different functions (as explained in ref.1). During wiring of the first series of tubes, we observed some instabilities in the rigidity of the bench (alignment shifts of the tooling under constant temperature, untightening of screws etc). After wiring the module 0 tubes, we decided to reinforce the construction. We put an aluminium brace around its legs and an horizontal grid close to the ground consisting of horizontal cross-bars. We also placed vertical cross-bars connecting the legs and enlarged the base of the table. The two legs of the right hand side of the table are adjustable in height, while the left hand side of the table is supported on wheels, so that the whole construction can expand freely under temperature changes (**Photo 3**).

Since the reinforcement was introduced, about a year ago, the table was held under constant temperature of $20\pm 1^\circ\text{C}$. The alignment of the wiring tooling was checked often and no deviations were observed.

We have also introduced improvements in the wiring tooling:

- We have replaced the simple “crocodile” spring pliers *wire crimper* used, with two wire crimpers made in Protvino, using a pneumatic cylinder instead of the spring. The pneumatic cylinder uses lubricated compressed air of 8 atm. We have crimped a few thousand pins with the pneumatic crimpers and once or twice we had problems which required repair (by the producer) of both crimpers. On the other hand, the spring crimper is always reliable and we use it as a fallback solution.
- The pneumatic crimper, which crimps the pin after tensioning of the wire, is housed in a specially made support (**Photo 4**). This allows us to slide the crimper in and out of position mechanically without hand-supporting it during the crimping.

- We have mounted the two *tube clamps*, which are aligned with the gas crimpers, on special micrometric mounts, which allow movement in the x and y direction (**Photo 5**). This way the adjustment of the alignment of the tube/bench axis (see Appendix of ref 1) can be done faster and easier.

- We have incorporated the automatic tensioning process of the wire in the general DAQ program (see section 5). We have also increased the speed of the tensioning process which now takes 40 sec in total (less than 10 sec to get to the pretension value) and is performed in parallel with other wiring tasks.

- We overcame all previous difficulties concerning the scanning of the bar code, using an ALTEK MS265 bar code scanner. The information enters automatically in the data base.

4 Improvements in the QA/QC procedure

After the completion of the tube wiring, three QC checks are performed on the wiring bench:

- Measurement of the finished tube length.

This is performed by placing the tube in the *tube ruler*. This precision aluminium through, which is fixed on the table, has been specially hardened at IMMIG. The mechanical spring-mounted precision micrometer was replaced with one using a digital readout, which is automatically read by our DAQ program. The hollow aluminium cylinder used for the contact of the spring with the end-plug's back surface was replaced by a harder brass one.

- Measurement of the coaxiality between the end-plug axis and the tube axis.

As mentioned in ref 1, the tube is supported - on the end-plug precision surfaces - by means of two jigs made with spheres glued on the table and the angular difference is measured by means of a micrometer located two centimeters away from one of the spherical supports. We have placed a second micrometer on the other side of the tube, so we can measure both sides without re-positioning the tube. The first micrometer was rotated by 90 degrees, with respect to its previous position. This allows safer and faster insertion of the tube on the spherical supports. We measure the difference in μm when the tube is rotated on both sides. This displacement is then converted into angular difference between the tube and end-plug axis (eccentricity).

The displacement which the micrometer reads maybe due to either of the two facts :

- a) The axis of the tube and the end-plug are parallel to each other but do not coincide.
- b) The axis of the tube forms an angle of few mrad with respect to the end-plug axis.

We have investigated the source of the eccentricity by placing a second micrometer at a distance of 20 mm from the right hand side micrometer. We took measurements for about 50 tubes. The study of the results showed us that on the average the eccentricity was due to reason b) and that the second reading did not help, so that micrometer was removed.

- Measurement of the wire tension

The wire tension under the nominal temperature of $20 \pm 1^\circ\text{C}$, kept in our clean room, has to be within 5% of the nominal tensioning value of 350 grs. We decided to

introduce an additional check of the wire tension, in order to monitor continuously the production and have the possibility to intervene instantly, if this is necessary. For this purpose, each tube is supported by two clamps on the bench while a permanent U-shaped magnet is placed below the middle of the tube. The wire vibration frequency was measured using a specially made tension meter, which is described elsewhere (ref 2).

5 The data acquisition (DAQ) program and the local Database

During the wiring and QC tests, all relevant data are automatically entered in the local DataBase (DB). For the storage of the information an application in Microsoft Access originated from Rome 1 group (ref 3) was followed. The Local DB file is then modified by National Technical University of Athens (NTUA) in order to fill the QA/QC (ref 4) fields and by University of Thessaloniki in order to fill the chamber assembly entries.

The wiring DAQ program should perform the following tasks:

- Enter all relevant data required by the DB prior to the start of the wiring.
- Follow the procedure of the wiring step by step, while recording all relevant data at each step. The procedure is speeded up since the program prompts with questions about the required data.
- Perform the wire tensioning process, including the pre-tensioning plus relaxation.
- Record in appropriate places the information concerning the QA/QC tests performed in our site.

The program was written using the Lab View software tools. We use a conventional PC to which all relevant data are input through, either a DAQ² card or an RS-232 interface. In **figure 1**, one can see the display of the program.

As a first step the operator has to enter a set of parameters, which relate to the origin of the materials used for the tube assembly. These parameters form a cluster of pointers to specific tables giving the information about the locators, the wire and the end-plugs that are being used. These parameters remain constant for a large number of tubes and get changed by the operator only if new material is introduced. At the same time, the user has to fill the second cluster, which includes the tube length batch, the initials of the operators and the humidity. Although the latter parameter is almost constant during the day, an often check ensures that the field has the proper value.

Before the actual threading of the wire through the tube, the operator has to enter the bar code stamped on the tube. This is done by the bar code reader, which is connected to the keyboard. In some cases the tube has to be rejected at that point, because it fails the visual inspection by the operator (has scratches or dents etc). If this is the case, the operator enters a relevant rejection code and fetches the next tube. This can also be done in any step during the process, whenever a tube must be rejected for any other reason. In the opposite case, the operation proceeds and the software gets ready to perform the pre-tensioning and tensioning procedure. This is done by program-controlling the step-motor, while getting a feedback from the three wheel tension meter. Three Boolean indicators inform about the status of the pretension and

² National Instruments Co, PCI –M/O-16E-4

the tension. When the tensioning is complete, the program stands by and waits for the operator to crimp the wire and then relaxes the tension.

The next step is the automatic recording of the finished tube length. The operator places the finished tube in the tube ruler, positions the hollow brass contact cylinder and-when ready- the program reads the micrometer value. The operator checks the number on the screen, and if necessary repeats the measurement. The value read is only the difference between the finished tube and a reference tube, but the program adds the length of the reference tube and stores the actual length in the DB.

Next measurement is the wire tension of the finished tube. The program waits until the operator places the tube and connects the cables at each end of the tube. The wire tension meter reads the resonance frequency, records the measurement temperature and the tension of the wire at 20°C is then calculated. The operator controls the reading on the screen and repeats the measurement, if necessary.

Finally, the program gets the date and the time of the wiring and saves all the parameters needed for the filling of the local DB with the proper order. The local wiring DB³ is periodically updated before exporting it to the other collaborating institutions.

The main features of this software are the friendly and instant interacting environment, while, at the same time, provides the information for the steps of each separate procedure.

6 Recovery of tubes with high leak current

The wired tubes, in order to pass the QA/QC control, have to have a leak current of <3.4nA, when operated at the working voltage of 3.4kV, supplied with a gas mixture of Ar/CO₂ (93:7) at 3bar pressure (absolute). This check is normally performed by NTUA for all tubes. In order to have a quick feedback on the day's production we -at the UoA- have established a simple set-up where we sample- test tubes at the end of the day.

The measurement set up is shown on **Figure 2**. The tube is placed on a dielectric support, connected to the gas flow, connected in series to the limiting resistor R₁ (10 MΩ). The leak current was measured in the voltmeter, which is connected in parallel with the calibrated resistor R₂ (1 MΩ) to the ground.

Our measuring device has been cross-calibrated with the Keithley 2000 Electrometer used by NTUA for this purpose, and found in agreement.

Sample measuring each single day, we monitor continuously the wiring conditions. We have previously found that up to 10% of our tubes had leak rates exceeding the above mentioned limit. After carefully study and efforts to reproduce the conditions for producing a tube with high leak current, we arrived at the conclusion that the high leak current should be due to bad parts of the wire.

In order to recover the bad tubes we investigated the application of reverse HV (RHV) to the tubes, namely inverting the polarity of the HV (connecting the +HV to the wall and grounding the wire).

Since September 1999 we have been applying RHV to the first set of noisy tubes (tubes of module 0) and have been monitoring their behavior.

We have found out that in order to establish a long term leak-current reduction one has:

³ <http://www.phys.uoa.gr/Atlas/MDT>

- To apply RHV and wait until the current under RHV reduces and reaches a steady value ($\langle I_{rev} \rangle \sim \text{const}$). This usually takes a few minutes and the inverse current reaches values of few hundreds nA's.

- In most cases the fulfilment of the above condition is enough to recover the tube. That is, when the normal HV is applied again, the leak current is under the specified limit. In few cases this is not true and we had to repeat the application of the RHV. In these cases, one has not only to wait for the fulfilment of the $\langle I_{rev} \rangle \sim \text{const}$ condition but, in addition, for the fluctuation of the reverse current to become close to zero, namely $\Delta I_{rev} \sim 1-2 \text{ nA}$.

In one fulfills both the above conditions, then all tubes (sample of about 50 tubes) were recovered.

In addition we have checked the long term behavior of the recovered tubes over time intervals varying from hours, days, months up to one and half year later. In all cases, the low values of the leak current remained stable timewise.

7 Experience, results

From June 1999 till the end of January 2001, we have wired almost 4000 tubes for the BIS chambers without facing major production difficulties. However, our aim during this initial period was to optimize the wiring procedure, in order to arrive the sooner possible to a steady improved production rate, minimizing simultaneously the amount of failures. We achieved an average wiring time of 5 min/tube (involving two operators), including all the QC tests described above. Another 2 min/tube for the end-plug assembly must be added to the above mentioned time interval, although it can be performed in parallel, if additional personnel is available. An additional average time of about two hours/day must be added, to account for all the rest of the tasks. This includes the daily start-up and end-of-day procedure, maintenance of the tooling, transfer and unpacking of components and packing the wired tubes for shipment to the NTUA for the QA/QC tests.

In **figure 3**, the number of wired tubes per production day in the period September 2000 to January 2001 is presented. This period corresponds to approximately 100 working days. In this plot, three periods of one week each with no tube production can be observed. The first two periods of interruption were due to lack of components. The third one, in January 2001, was due to human illness. Nevertheless, in this plot a positive slop in the production rate can be observed, showing that under the proper conditions, a daily production above our quota (35 tubes per day) can be achieved.

The finished tube length, which is measured and registered in the database for all the tubes is presented in **figure 4**. It can be observed that the distribution is nicely centered at the nominal value, having tiny tails⁴ compatible with an RMS of 30 μm . One should note that out of 3947 tubes produced, only 6 were found to be outside tolerances, out of which four were wired during the operator training period.

In **figure 5**, we show the distribution of the eccentricity measurement for both end-plugs of the tubes which were wired in December 2000. On the average we

⁴ This is the reason why a logarithmic scale has been chosen for this plot.

measure eccentricities well below 2 mrad (mean value of 0.8 mrad), which implements quite a trustworthy alignment scheme and poses no difficulties in the assembly of the tubes on the chamber assembly jigs.

The wire tension distribution results, as measured on our wiring table are presented elsewhere (ref 2).

In general, with the improvements of our wiring and QA/QC procedure together with the fallback solutions available through experience, we feel confident that any problems that might appear will be spotted fast enough ,so as not to disturb the production.

8 Summary

Using our improved wiring line we wired 10% of the total tube production without facing any problems. We used automatic feeding of the wire by a vacuum force, high pressure gas for the tube crimping and an automatic wire tensioning device. On the wiring table we implemented three additional QA tests. Namely, the measurement of the finished tube length, the measurement of the coaxiality between the tube and the end-plug axis and the measurement of the wire tension. The net wiring time per tube, including the QC tests is 5 minutes, while the checking/cleaning/preparation of the end-plugs takes about 2 minutes

We expect to continue the BIS production, without any major interventions, except maintenance, for the next three years.

Acknowledgements

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References

- (1) Atlas Internal Note ATL- MUON-2000-014
<http://www.phys.uoa.gr/Atlas/MDT/Note.html>
- (2) The MDT BIS tension meter (Atlas Internal Note-under submission)
<http://www.phys.uoa.gr/Atlas/MDT/Note.html>
- (3) <http://Global-MMPDB.roma1.infn.it>
- (4) Atlas Internal Note ATL-MUON-2000-019

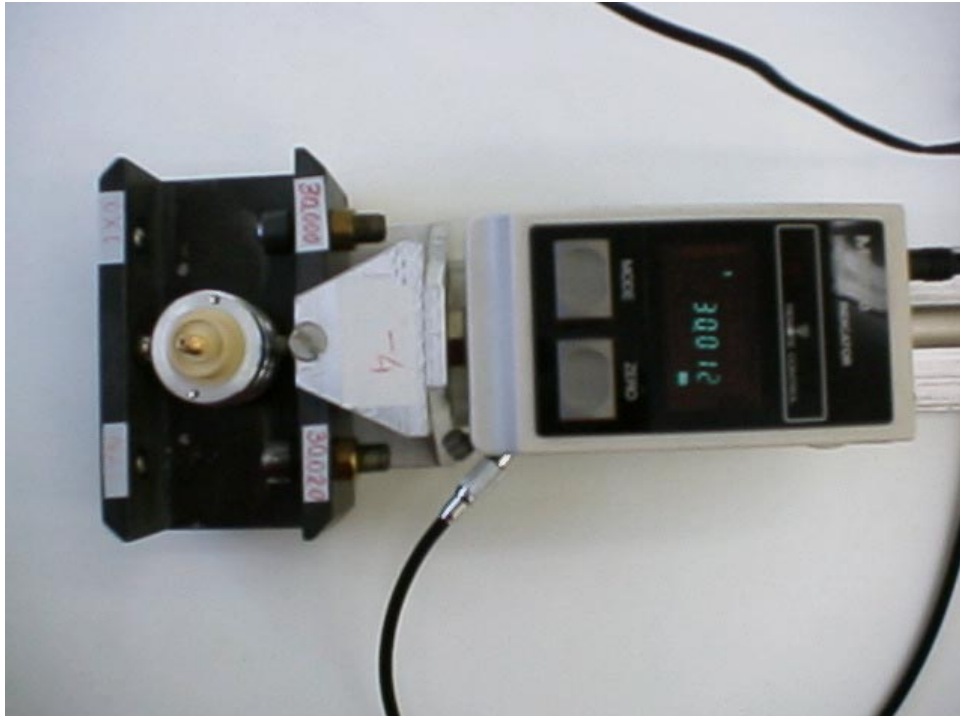


Photo 1 : Go/no-go gauge with micrometer for the end-plug acceptance test prior to assembly.

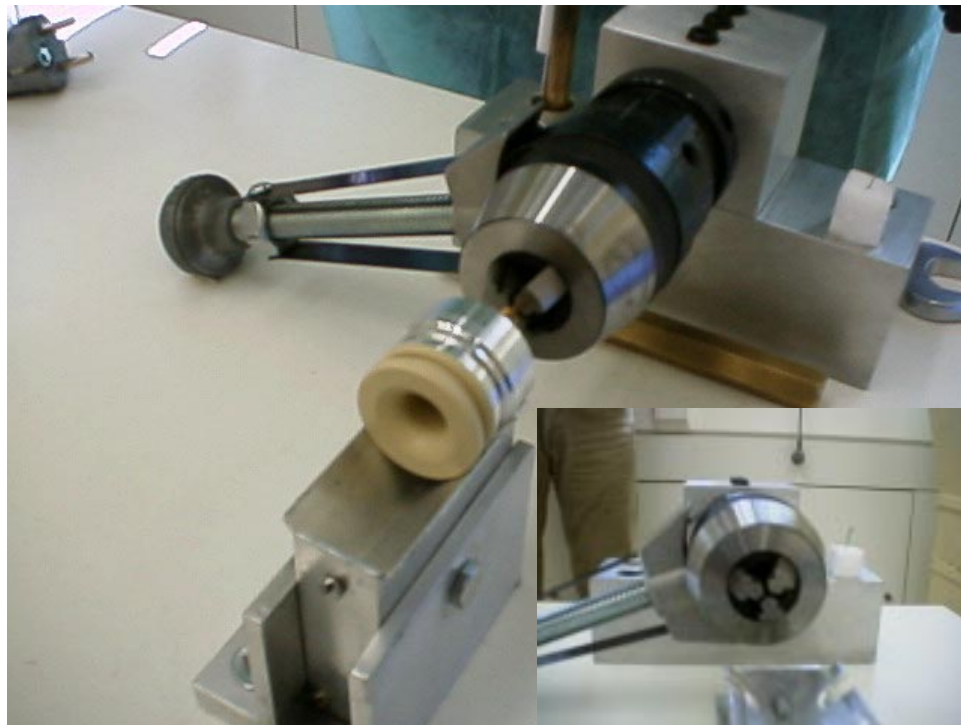


Photo 2 : Tooling for copper pin crimping on the brass sleeve. On the left lower corner the insert shows the contact point geometry.

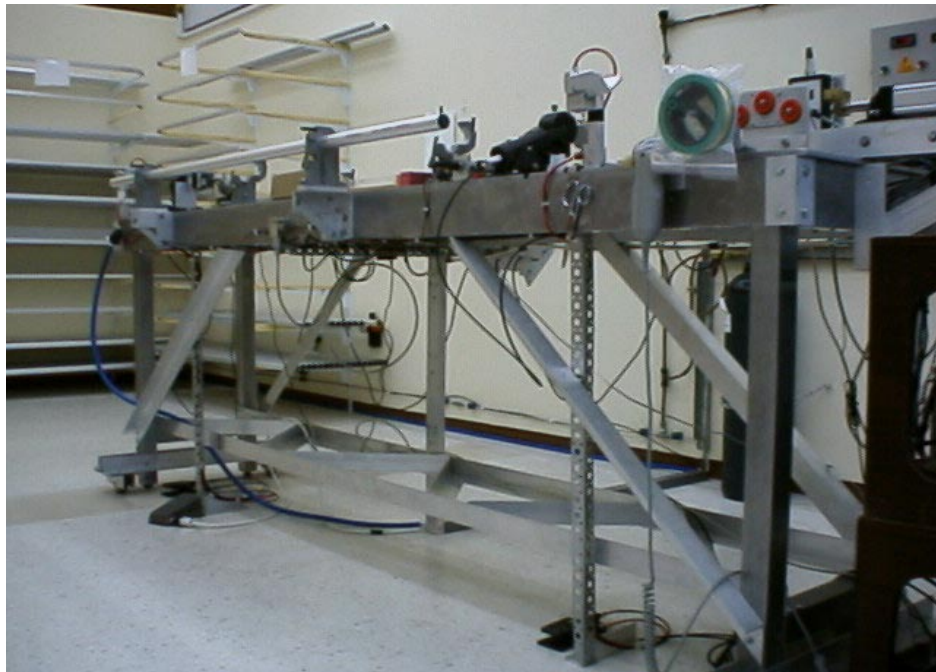
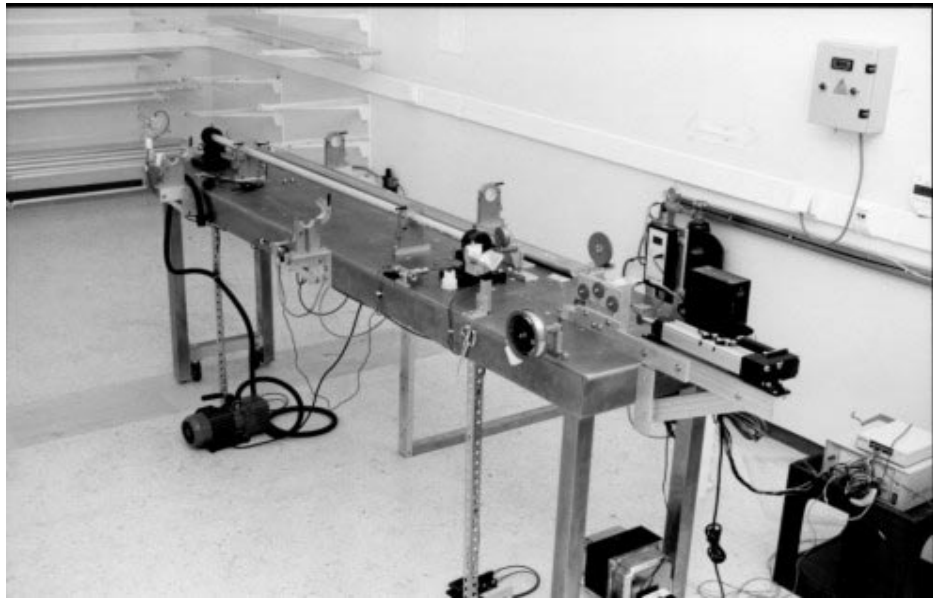


Photo 3 : Upper: View of the wiring table during Module 0 production.

Lower: View of the wiring table after the reinforcement upgrade.

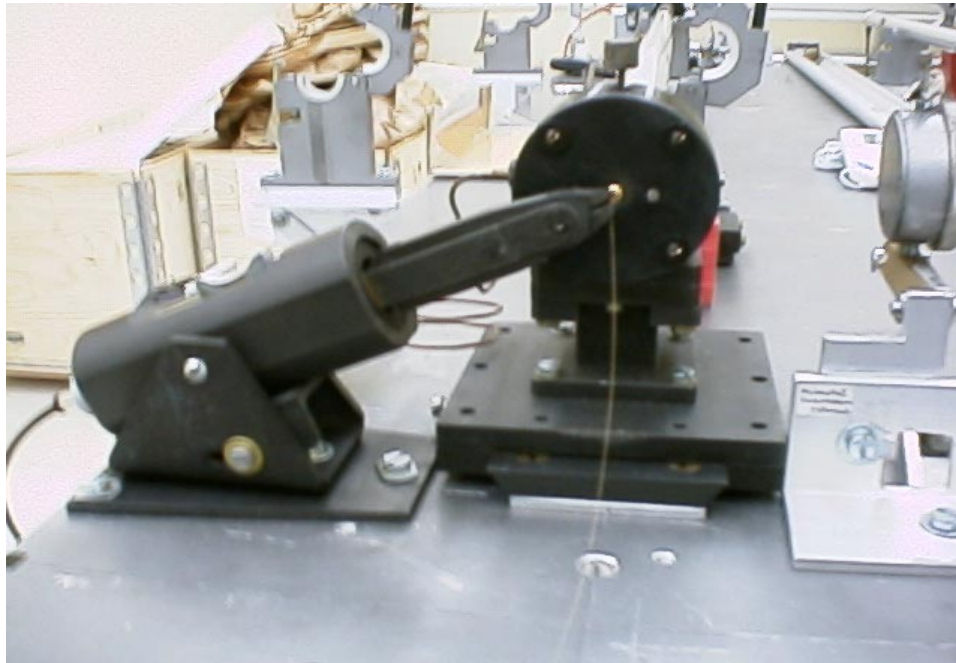


Photo 4 : View of the wire crimper holder together with the gas crimper.

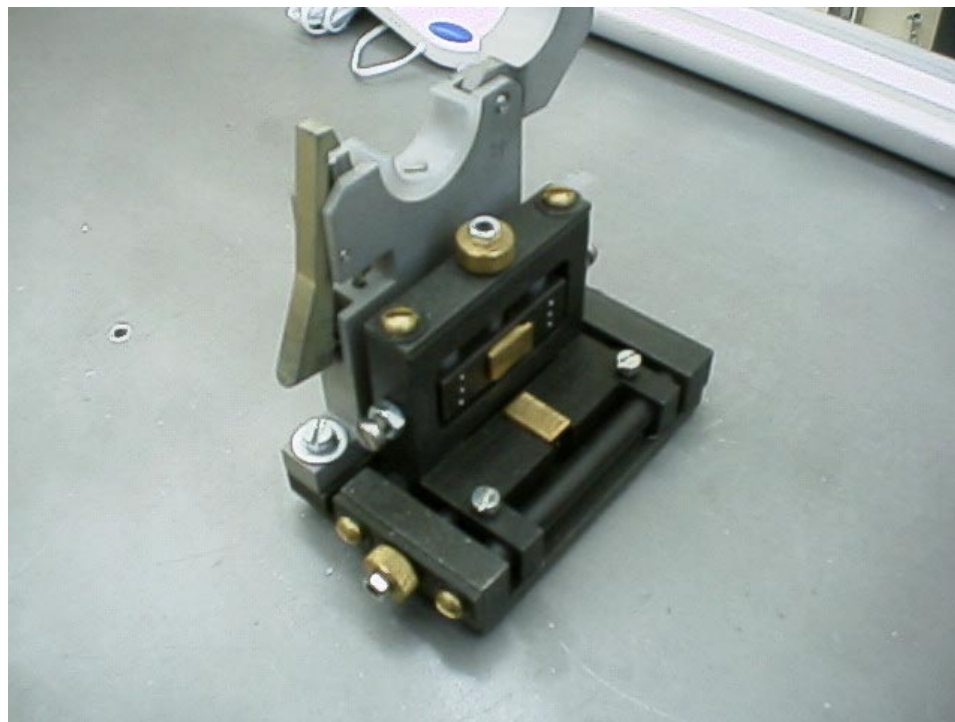


Photo 5 : The micrometric adjustable mount of the tube clamp, which can move in two dimensions.

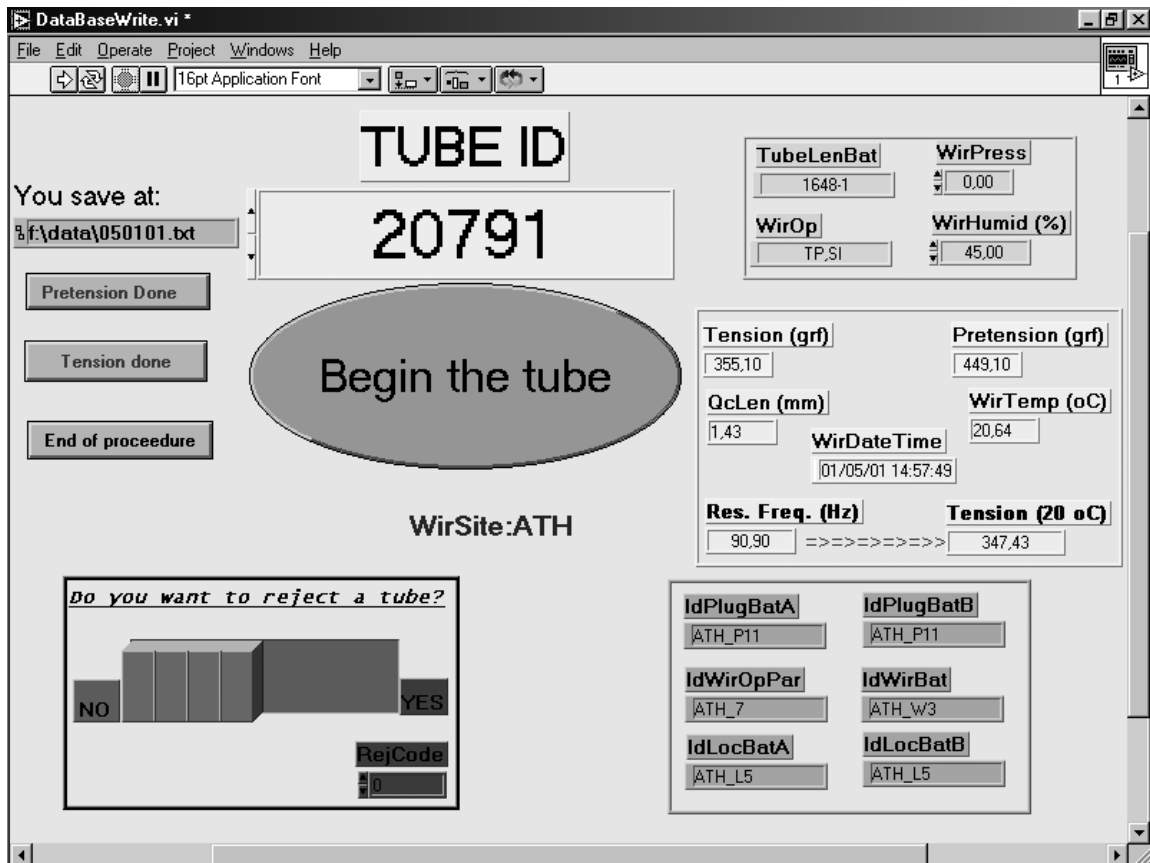


Figure 1 : The operator PC screen, when the automatic wiring application and data acquisition program is running.

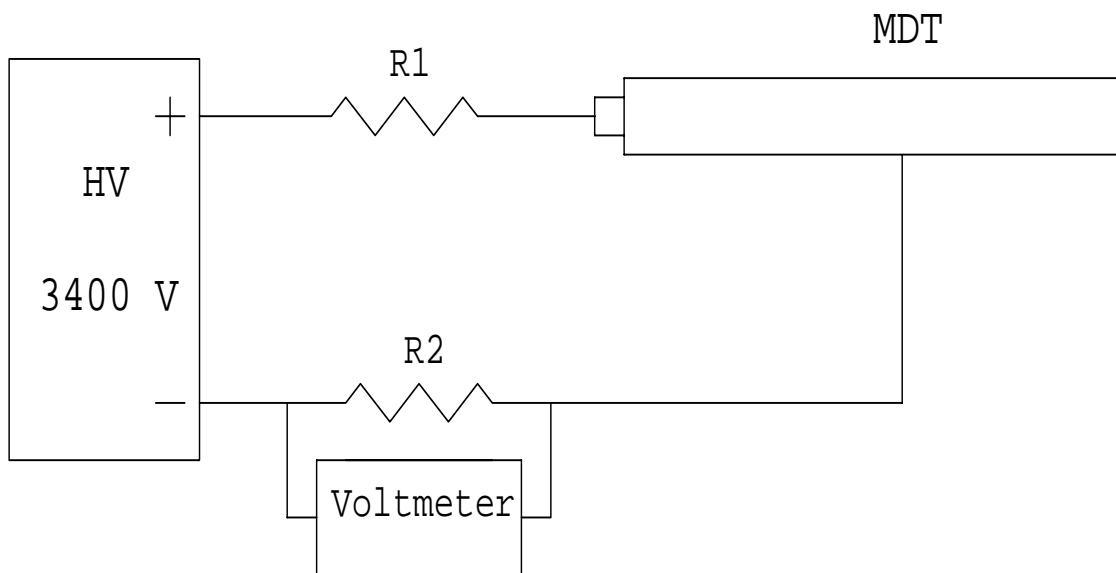


Figure 2 : Set up for leak current measurements

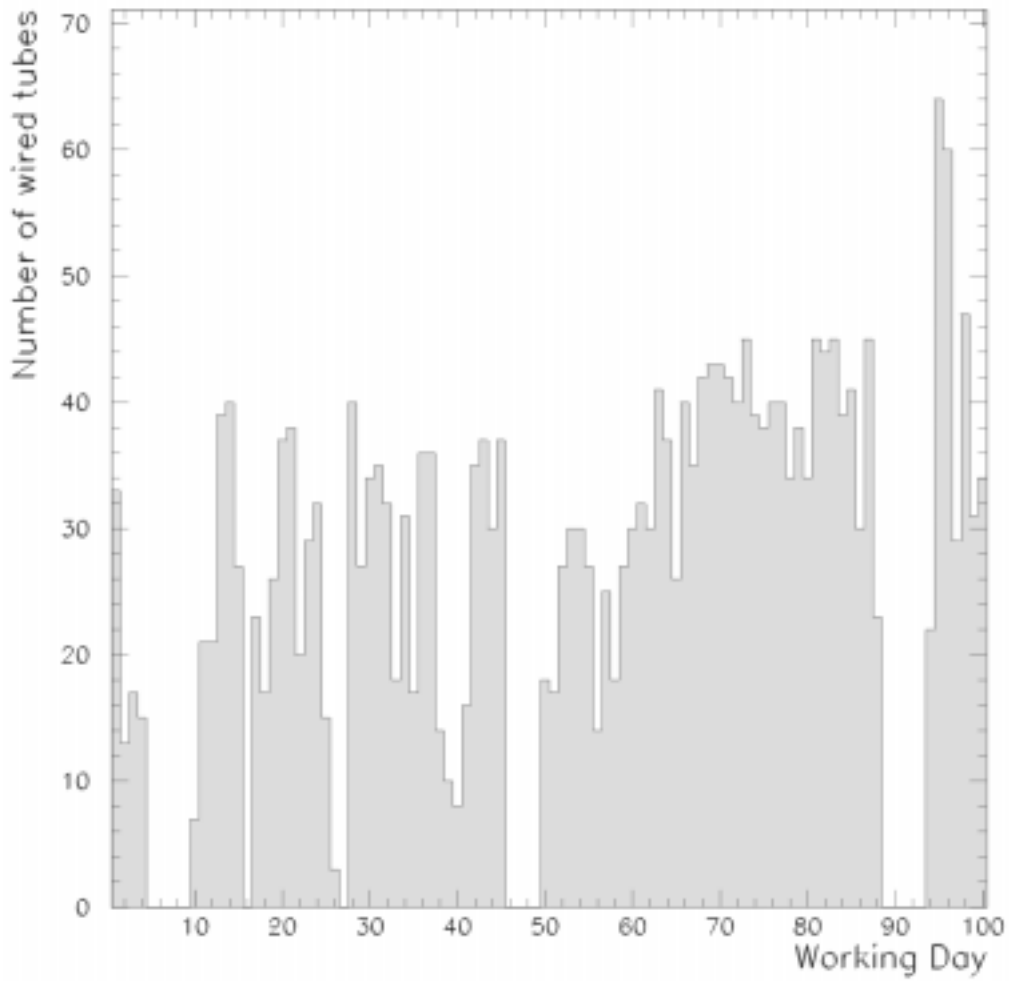


Figure 3 : The number of tubes produced per day in the period between September 2000 to January 2001, corresponding to approximately 100 working days. The gaps are explained in the text.

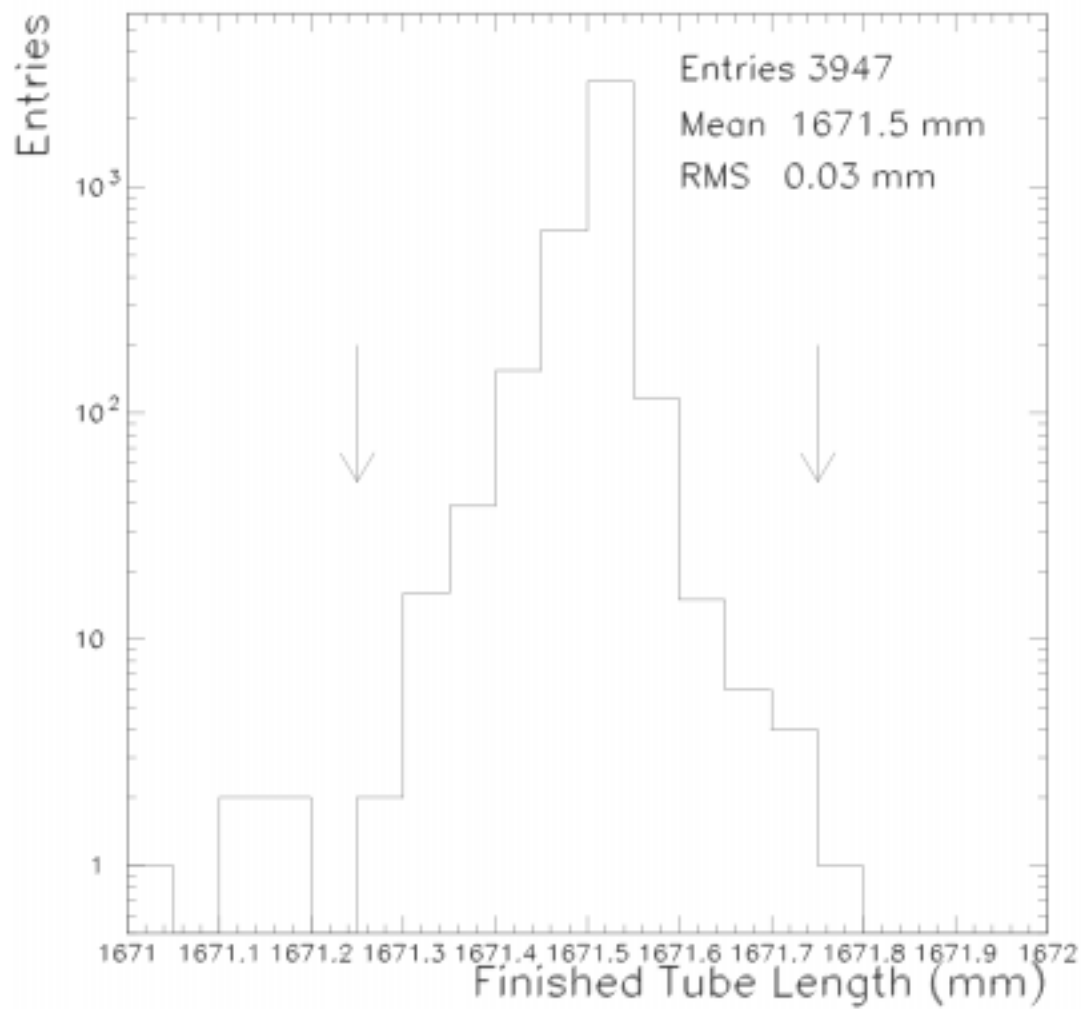


Figure 4 : The finished tube length distribution, for all tubes wired until the end of January 2001.

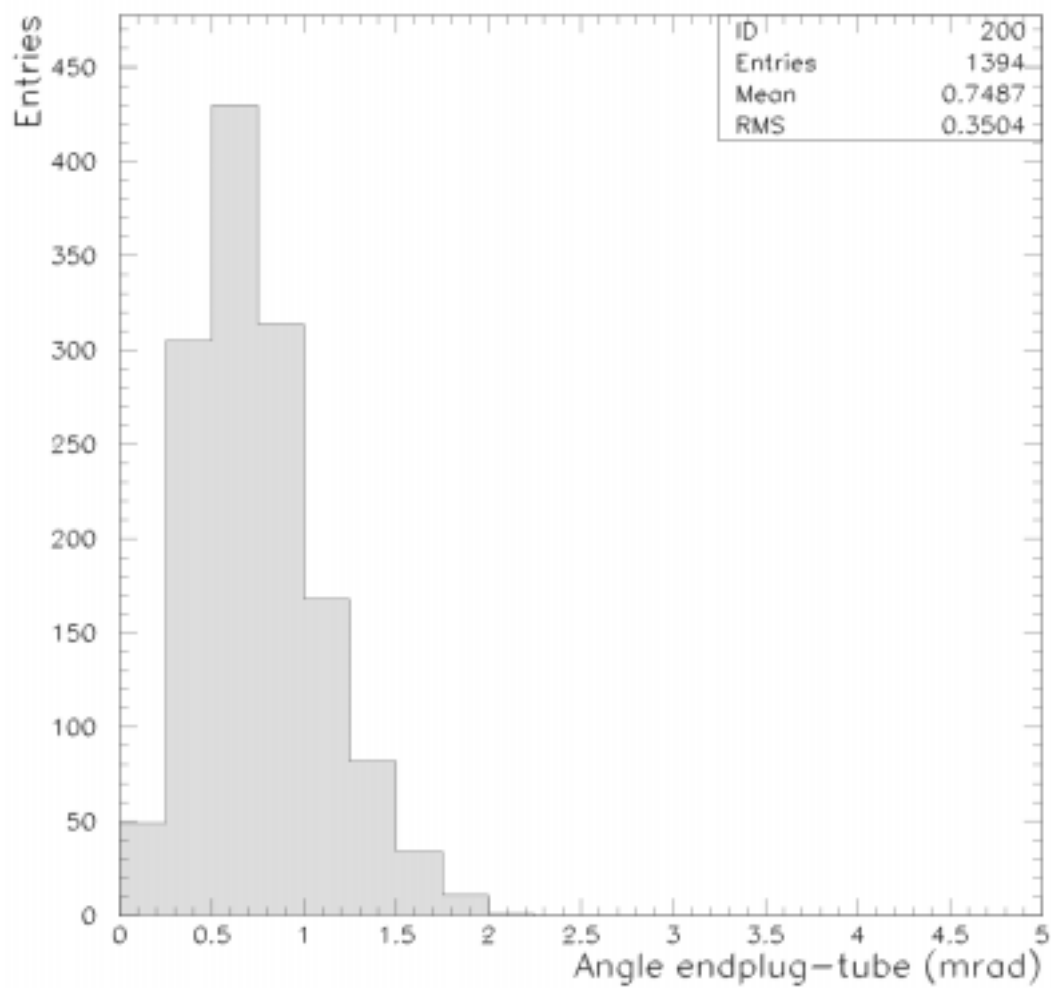


Figure 5 : Distribution of the angle difference between the tube and the end-plug axis. Measurements for both end-plugs are presented for the tubes produced in December 2000.