EXPERIENCE ON SERIAL PRODUCTION OF THE QUADRUPOLE MOVERS WITH SUBMICROMETRIC REPEATABILITY FOR THE EUROPEAN XFEL*

J.Munilla#, J.Calero, L.García-Tabarés, A.Guirao, J.L.Gutiérrez, T.Martínez, E.Molina Marinas, F.Toral, C.Vázquez, CIEMAT, 28040, Spain
C. Martins, E. Ramiro, F. Ramiro, RAMEM, 28027, Spain
J.A. Gorrotxategi, B.Junkera, M.Tarragual, A.Urzainki, HTS/ZEHATZ, 20850, Spain

Abstract

CIEMAT is in charge of the design and manufacturing of the quadrupole movers with submicrometric repeatability for the XFEL.EU intersections. Prototyping of these precision devices was successful but manufacturing them in a serial production scheme (101 units) implies some changes at design, fabrication procedures and quality controls. This paper will present some of the main problems and solutions adopted to transform a prototype made at a research facility into a serial production at a conventional industrial company. Also, it describes the inspection and tests, the quality controls and reporting procedures. All the devices have been validated and recepted. This paper describes the adopted procedure and the performance of the serial units.

INTRODUCTION

Quadrupole Movers (QM) for the European XFEL [1] will be installed in the intersections between each pair of undulators. CIEMAT is fully responsible for the conceptual and engineering designs. 95 units are part of the Spanish in-kind contribution and 6 additional units were ordered by DESY.

During the research and development stage, three prototypes have been built from 2009 to 2012 [2]. In the last one, some design changes have been included to optimize serialized production and reduce costs at industry. XFEL-EU has given final acceptance on the prototype and technical specification for serial production in 2012. The production of the QMs has been split in two bunches to reduce risks, in special with the tight schedule. CIEMAT allocated two contracts for half of the serial production each one in 2013. Spanish companies RAMEM and HTS/ZEHATZ were awarded with the contracts.

FUNCTIONAL REQUIREMENTS

The complete list of parameters of the XFEL quadrupole movers has been published elsewhere [2]. Submicrometric repeatability for movements in 2 axes (horizontal and vertical) is the most challenging one. The vertical load to withstand is 75 kg, while small lateral forces are admissible (about 10 N).

In order to achieve a compact design, a wedged configuration was chosen for the vertical movement. Both axes include a high precision linear actuator and a closed-loop control system fed by two LVDT sensors. Precision adjustable limit switches and hard stops are needed to maximize quadrupole travel length without interference with the beam pipe.

All the QMs adjustments must be measured and reported. This information will allow parametric control and calibration for the intersection control system. Moreover, all the QMs should be interchangeable apart of these parameters.

QUALITY AND DOCUMENTATION REQUIREMENTS

The main objective of the quality assurance system is to guarantee the achievement of the technical specifications. Both manufacturers have created and maintained a quality management system (QMS) according to UNE-EN ISO 9001 and UNE-EN-9100 standards.

Also, to ensure quality and integrity of units from first manufacture steps to final reception at XFEL facilities, CIEMAT has designed a procedure based on three reports for each unit:

1. Manufacture Report includes materials and components certificates and metrology reports in order to ensure traceability. It is intended for internal use to prevent malfunctions or potential problems before assembling and testing.
2. Validation Report includes final repeatability test results, adjusting parameters and the verification of accomplishment for all specifications before delivery. This is uploaded to XFEL.EU document management system (EDMS) for future references. This report is made by manufacturer.
3. Reception Reports include additional verifications and tests after delivery. This report is done by CIEMAT as cross-check and it is also uploaded to EDMS. Any possible deviation or problem during transportation can be detected.

In addition to documentation explained above, special procedures have been stablished:

- An accessible code is permanently engraved onto each part in an area that does not affect its operation or the engineering tolerances. At the same time, it

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#javier.munilla@ciemat.es

has to be visible once the QM is assembled (if possible).

- A conformity certificate for each QM has been released by the manufacturers. It confirms that the QM has been produced according to specification and that all requirements have been checked.

XFEL stores all production data in EDMS system for document management. All documents created for the quality assurance of the QMs, such material certificates traceability tables, dimensional controls, validation and reception reports or conformity certificates are recorded in EDMS.

QM FABRICATION

Based on the experience developed during prototyping, some critical points have been identified:

- Stiffness of each subassembly is critical, so a solid part is preferred instead of small parts coupled together.
- Preload on bearing guides and linear actuators must be carefully applied and checked.
- Special environmental requirements must be preserved to reach specifications. Use of clean, smooth and isolated metrological granite is mandatory. Even electrical noise coming from power supply could damage the LVDTs measurements. EMI filters are included inside the QM. Measurements must be done in a temperature-controlled room.
- Big effort has been made to develop a step-by-step procedure to figure out any problem at the earliest possible stage.
- A complete ready-to-use experimental setup (hardware & software) was developed by Ciemat. This is an autonomous procedure, non-sensitive on the supplier or client measurements. This will ensure reproducibility of results and calibration parameters. Same system is also used for validation (Fig. 1).

Figure 1: Setup for validation procedure. All HW and SW needed to control and measure the QM was provided by CIEMAT.

Quality documentation from raw material certificates is checked before manufacturing the parts. Metrology control is mandatory, and a subset of critical dimensions is revised and written in the manufacture report.

Using this procedure, once the device is assembled, some specifications are automatically fulfilled. But others like for example repeatability results and general quality of movements, must be checked with a special set of cycling movements.

QM VALIDATION

Validation procedure includes checking of limit switches and hard stops positions, tilt angles during movement and repeatability tests. Those measurements and tests are quite time consuming and sensitive to mechanical vibrations, thermal fluctuations, etc… Semi-automatic procedure developed by CIEMAT allow users to operate it remotely just by an Internet connection without disturbing the system. Manufacturing of such precision units and testing in industrial environment is challenging. Remote test operation allows carrying these tests at nights, when industrial areas are quiet, without traffic vibrations or electrical noise.

Of course, validation procedure cannot start if any non-conformity was found at manufacturing report. In the same way, as accepted and agreed with XFEL.EU for the prototypes commissioning, a set of automated cycles is mandatory. The hardware setup supplied by CIEMAT to the manufacturing company is automatically doing the whole process: Control of movements (same control strategy as expected for the real accelerator) and saving LVDT readings and external micrometer values for each movement.

Once the complete set of tests is finished (about 1000 movements in both axes), data is automatically processed. All relevant statistical data, including repeatability for different kind of movements, is calculated. Additional processed data is grouped in a convenient way (specific statistical results, comprehensible graphics). Then it is saved as a PDF report. This will provide easier understanding of any possible malfunction or lack of repeatability. In case that any specification is not fulfilled, the device could be adjusted or repaired according to this detailed information. Moreover, this procedure eases the management of the manufacturing know-how improving learning curve in manufacturing and adjusting the subsequent units.

DELIVERY AND RECEPTION

Each QM weights around 20 kg. It is a precision machine designed to operate in a scientific and controlled environment. Even when its design is as robust as possible, transport and delivery to XFEL.EU facilities can be dangerous. To avoid any risk, some points have been taken into account:

- Blocking system consisting of detachable screws. Two screws per axis. Special place is foreseen in each QM to store these screws once they are installed (Fig. 2).
- Double box concept to minimize impact effects on the QMs packaging. Dumping material is filling the space between both boxes while QM is firmly fixed to the inner one. So that, any movement is absorbed by the relative movement between boxes. Besides, QM is placed inside a sealed plastic bag with humidity protection. This concept also provides reduction of risks on QM contaminations from dumping material and high thermal protection is achieved.

Reception tests have been carried out by CIEMAT personnel in XFEL. Then, results from validation report and integrity are checked again in final destination after delivery.

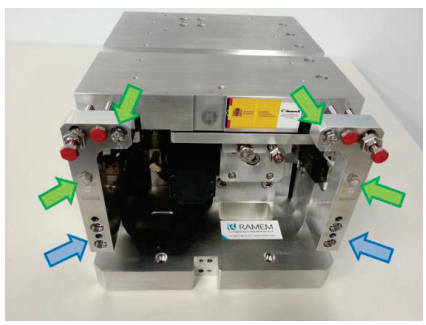

Figure 2: Transportation blocking screws (Green). Once installed they can be placed in holes marked by blue arrows.

TEST RESULTS

As mentioned above, the most challenging and sensitive specification to achieve is the submicron repeatability. It is double-checked, first at manufacturing stage and later as part of the validation procedure. Figure 3 shows repeatability results along the serial production. Maximum repeatability values found are 0.78 and 0.77 microns (horizontal and vertical). Achieved repeatability values are quite constant during all production. Slight improvement can be observed for the repeatability results due to the experience gained by manufacturers.

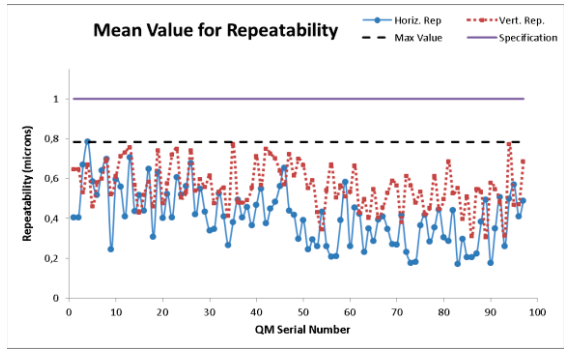

Figure 3: Repeatability results for serial production.

Adjustment results for limit switches are measured with different hardware units: validation rack at the companies, and a real Intersection Control Rack (developed also at Ciemat [3]) in XFEL during reception. This procedure serves as cross-check for this important adjustment. (Figure 4)

All the 97 units delivered up to date have been recepted and accepted successfully. These are some highlights:

- 100% of QMs achieve submicron repeatability. More than 70% of QMs score better than 0.50 and 0.65 for horizontal and vertical axes.
- Just one nonconformity has been found (non-critical). It has been accepted by XFEL once this has been advised in the EDMS reports. It does not affect performance. It is just related to the pre-alignment procedure during installation at the intersection.
- Just 1 QM has been returned to manufacturer. It was not adjusted properly, so that reception tests noticed the problem. Once it was readjusted, it passed the tests and it was finally accepted without any special notification.
- Minor in-situ readjustments were needed for 3 QMs, probably arised from shipping vibrations or impacts. Two of them had impact sensors broken at outer box so special care was taken in reception test. Reception tests detected the problem and finally they passed successfully all the tests.

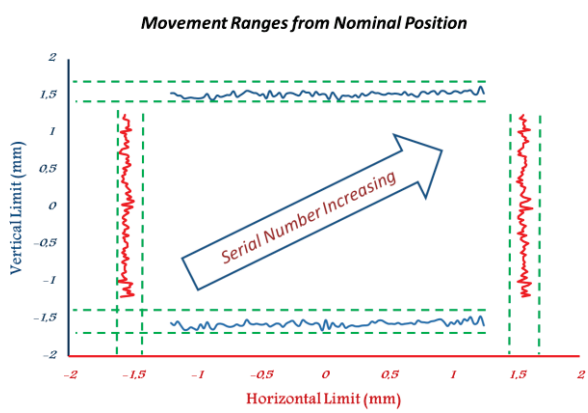

Figure 4: QMs movement range measured in accordance to the travel length specification.

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CONCLUSION

Serial production of QMs has been carried out by two Spanish companies (RAMEM, HTS/ZEHATZ). CIEMAT has prototyped the QMs and follow-up the orders for serial production. Exhaustive quality control based on a semiautomatic procedure resulted in a very proper system to ensure great results within tight schedule. Procedures exposed in this paper provided an adequate information flow between different industrial companies, prototype designers at a research center and a large European scientific facility. Any possible risk has been detected in advance, all relevant information is perfectly classified and traceability is ensured. 97 units have been successfully delivered and accepted by March 2015, in accordance to the schedule.

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