OPERATION EXPERIENCE WITH HALF CELL MEASUREMENT MACHINE AND CAVITY TUNING MACHINE IN 3 YEARS OF EUROPEAN XFEL CAVITY SERIES PRODUCTION

J.-H. Thie, A. Goessel, J. Iversen, D. Klinke, C. Mueller, A. Sulimov, D. Tischhauser
DESY, Hamburg

ABSTRACT

For the European XFEL superconducting cavity series production DESY supplied the two cavity vendors with two machines each, for production key functions: Half Cell Measurement Machine (HAZEMEMA) and Cavity Tuning Machine (CTM).

During three years of cavity series production a lot of experience was gathered about the influence of company specific surroundings and production quality on cycle times, machine drop outs, general stability time of machines and parts subject to wear.

Significant factors on cycle time for tuning operation like temperature stability and drift during tuning and measurements, precision of cell trimming before welding and tuning and geometrical factors are shown.

RF-aspects of tuning and production quality control such as additional measurements for TM011-mode to estimate quality of its damping are presented.

The performed full cavity RF measurement exceeds XFEL specifications and allows additional quality control on welding shrinkage stability and its homogeneous distribution.

INTRODUCTION

The correct mechanical trimming of cavity half cells, dumb bells and end groups is the precondition to reach the correct frequency and length of the welded and surface treated cavity.

For these key functions in total four machines, two HAZEMEMAs (Fig.1) and two CTMs (Fig.2) were supplied to the companies fabricating cavities. The general functionality of the machines was presented in previous papers [1, 2, and 3]. That is why no detailed information related to machinery functions will be given in this paper.

HAZEMEMA

For the previous prototype productions it was sufficient to perform all necessary half-cell and sub component RF measurements manually.

For the mass production all RF measurement and calculation functions were implemented into a highly automated machine. The HAZEMEMA design including control electronics, software and all interfaces with XFEL and companies databases was done by DESY for the European XFEL.

Figure 1: HAZEMEMA in use at the company.

For quality control and fulfilment of cavity RF requirements given by European XFEL specifications it is necessary to measure the RF properties of single half cells, completed dumb bells, pre turned end half-cell units, and complete cavity end groups before and after mechanical trimming.

Single cells are controlled by lots with a lot size of about 20%. All other named parts are measured 100%.

Based on 840 European XFEL cavities fabricated within 3 years, more than 2800 normal half cells, 5000 end groups and end group sub-components and around 14,000 dumb bell measurements have been performed with two HAZEMEMAs, i.e. 22,000 measurements in total.

HAZEMEMA SERVICE AND REPAIR CONCEPT

To ensure the required production quality, it is absolutely necessary to regularly control machine precision and RF calibrations. Therefor a regular service was scheduled every 6 months.

The performed checking of both machines did not reveal any relevant deviations from RF calibration.

Due to the tight European XFEL time schedules no production delays could be accepted. Both companies should have enough sub components on stock so that

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cavity production could have gone on for about two weeks without HAZEMEMA. This goal was never completely achieved.

This goal additionally raised the pressure on machine stability and availability in general.

Accompanying the design of machines a service and repair concept was developed. Instead of having lots of spare and wear parts on stock it was decided to build up a complete spare machine. The spare machine should be delivered and commissioned at companies in case of a hard machine failure within 10 days.

Fortunately no hard errors showed up so a machine exchange was not necessary.

The longest machine down time for HAZEMEMA was caused by a SPS total malfunction. A repair at companies' side within 6 days was possible.

Generally HAZEMEMAs showed very good machine stability. During production ramp up smaller design changes were necessary due to wear parts with early wear out. E.g. rollers and wires from counter weight for measurement head showed several defects at first state.

On one hand side this is related to wear parts which did not achieve specifications for life time given from manufacturers, on the other hand side during ramp up machines were operated partially 7 days per week with up to three shifts. This caused a much higher machine load than foreseen to be covered by a regular service every 6 months.

During the entire cavity production after ramp up there were nearly no more complete machine down time in the last two years of European XFEL Cavity series production.

SUMMARY HAZEMEMA

During three years of series cavity production both HAZEMEMAs at the two companies have proven their abilities for large industrial series productions.

All requirements related to given specifications were completely fulfilled.

Furthermore the service and repair concept including regular software updates and troubleshooting via remote access to machines worked as planned.

No production stops were caused by possible machine failures, which is the largest success to those who designed and supported the machines during three years of cavity production.

CAVITY TUNING MACHINE

The Cavity Tuning Machine design, control electronics, software and all interfaces with XFEL and companies databases was done by a collaborative effort among DESY, KEK and Fermilab [2].

Main targets for machines were to enable companies to measure and tune cavities to required mechanical and RF specifications in adequate cycle times.

Figure 2: CTM in use at companies.

In the different production stages each cavity for European XFEL cavity series production measured or tuned on the CTMs up to 5 times.

Standard cycles are:

- cavity field flatness and straightness measurement after welding,
- if needed a straightening (open tuning after welding),
- after first chemical treatment, coarse and precision tuning,
- cavity tuning with He-tank-transitions-ring and –bellow,
- measurement of cavity in helium vessel.

Within 3 years more than 3500 tuning operations were performed.

Additionally more than 150 cavities needed an additional straightening after welding. As this procedure was not foreseen during machine design it has a particular importance.

The straightening of cavities after welding is necessary to make the cavities fit to frames, to production tooling and for electro polishing (EP). Regarding this cavities to be straightened are not annealed. They are much harder with a completely different elastically behaviour than foreseen in machine design.

This leads to a much higher mechanical load for the machines and thus earlier wears out of several main components (Fig.3).

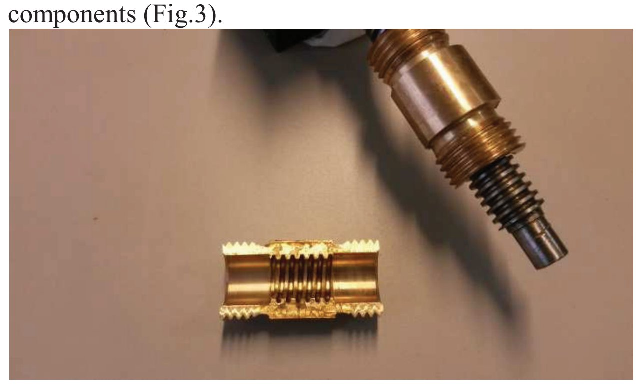

Figure 3: CTM spindle and gear box with early wear out.

In addition to performed tuning operations more than 1000 measurement operations were done with CTMs.

Generally CTMs showed very good machine stability after several upgrades.

Due to experience from first commissioning of machines at DESY several design improvements before production ramp up at companies were done [3].

Similarly to HAZEMEMAs exceptionally early wear out of wear parts, a few defects related to accidental misuse of machines and several failures related to machine software and electronics, no hard errors showed up within three years of cavity production.

The longest machine down time for CTMs was 9 days caused by a defect of electronics as result of a defect stepper motor. A repair at companies' site was done in a collaborative effort from Fermilab and DESY.

CAVITY TUNING MACHINE SERVICE AND REPAIR CONCEPT

To ensure the required production quality and machine stability, it is necessary to regularly check machine calibrations and condition of wear parts, drive chassis, spindle gears, all over machine mechanics, RF cablings and machine sensors. This was done by a regular service scheduled every 6 months.

Additionally the condition of machine was regularly checked via remote access. This remote access was also used for the support of the tuning operators at the companies during tuning and troubleshooting.

Accompanying the design of machines a service and repair concept was developed. Similarly as for HAZEMEMA it was foreseen for both companies to have enough cavities on stock so that no production stop would be caused if a machine down time of up to 10 days occurred. This goal was not completely achieved during entire production.

Due to the complexity and price of the machines and their different configurations at the two companies, no complete spare machine was built up.

As DESY is in responsibility for the machine's availability a reasonable stock of spare parts and wear parts was established.

The number of parts available from DESY stock is based on experience, how often a part or electronic device shows an error, how long the period of delivery or fabrication time for effected parts is and what is the standard lifetime given from suppliers for wear parts.

Furthermore tooling for mechanical service, electronic diagnostics, repair and standard wear parts are kept in transport boxes for immediate shipment.

Together with the large stock at DESY and a well-trained service team for repair and troubleshooting it was usually possible to be at the company's site within two days in case a repair of machines was necessary.

After the ramp up phase of production with a very high load for the machines had been passed no longer machine down times showed up.

A lot of experience on lifetimes from sensor devices, wear parts and electronic components was gathered during production ramp up.

Based on this experience several parts and devices were preventatively exchanged during regular services in the prediction they will shortly quit operating.

With this practical knowledge from production experience and its predictions, it was possible to significantly reduce the number of machine down times in the second half of production.

CAVITY TUNING MACHINE CYCLE TIMES

The major motivation to develop the CTM was to reduce the necessary tuning time of a cavity and to decrease total cost in cavity production [4].

The target for the XFEL CTM is to perform a tuning operation in about 4 hours.

At the beginning of the production in general the named target times were achieved, but there was a significant difference between the two companies which was not completely understood from first stage.

This behaviour could not be explained, neither by differently experienced operating personnel nor by differences of machines or configurations related to the different treatment schemes at companies.

It was found that the most relevant important factor for a fast cavity tuning is the temperature stability during entire tuning operation and RF measurements.

RF measurement results and temperature are the most important values besides mechanical values to tune a cavity to the foreseen length, straightness, target frequency and field flatness.

Of cause, slight changes of temperature are compensated by calculations in CTM control software. Anyhow these calculations generally fit, but do not completely compensate errors caused by big and fast temperature drifts to fulfil the required RF specifications.

It was found that in case the temperature stability during tuning operation exceeds changes of about 0.2° C additional tuning iterations become necessary.

Furthermore it was found that during a full RF measurement, which takes about 20 minutes, the temperature has to be stable within 0.1°C. In case temperature stability exceeds 0.1°C, the field flatness may deviate from the predicted one and be out of required specifications. This as well may require additional tuning iterations.

In addition time has to be respected that the cavity body temperature can adapt to the room temperature at the CTM before starting measurements or tuning.

With this experience it can be partially explained, why during ramp up from production at one company significantly more tuning iterations were necessary.

After improvement of air conditioning system at one company together with improved work flows to ensure equal temperature of cavity compared to room temperature the average tuning cycle time could be reduced significantly.

The second relevant factor for achievement of the foreseen tuning cycle times and for explanation of the

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differences between the two companies is the fabrication quality in general.

It is quite clear, the better the geometrical properties of a cavity compared to theoretic properties are, the less tuning for a cavity is necessary.

It was not possible to quantitatively identify the influence from several factors. That is why they will only be named here and shown with some typical examples.

At first stage it was found that deviations from predicted cell or equator length / geometry require additional tuning iterations.

It does not matter if this was caused by over / under trimming of cells, no full penetration equator welds or even double equator welds. Further influence on geometry of cells is given by in-homogeneous distribution of equator welding shrinkage.

In general the behaviour of cavities affected by one of these fabrication quality problems is quite similar. Tuning such a cavity takes more tuning iterations than a cavity of better fabrication quality. This fact causes significant longer tuning cycle times.

Regarding cycle times for tuning operations it shall be clearly pointed out that all produced cavities – except those which have to be straightened before annealing - fulfilled or even exceeded the specifications for European XFEL cavity production. The predicted cycle times were also achieved.

It is the responsibility of cavity vendors to keep specified environmental factors and fabrication quality on a level that tuning is possible within reasonable time. In entire production one example proves this:

One cavity in very good fabrication quality was fully tuned by perfect thermal stability slightly below three hours.

In summary, only regarding the last phase of European XFEL Cavity series production, it seems to be possible to generally reduce cycle times for cavity tuning by about 25 % by enhancing production quality over the specified limits and improvement of surrounding factors.

ADDITIONAL MEASUREMENTS ON CAVITY TUNING MACHINES

In addition to the required measurement of frequency and field flatness for many cavities full RF-measurements before main EP and field distribution of TM011 mode was performed on CTM.

By means of analysis of full RF measurements of several cavities a good estimation on stability of cavity equator welding and its homogeneous distribution can be given [5].

The measurement of TM011 field distribution by CTM is a well-qualified tool to predict the results of HOM damping properties during cavity RF test at 2K and later for cavity properties when operated in accelerator module [6].

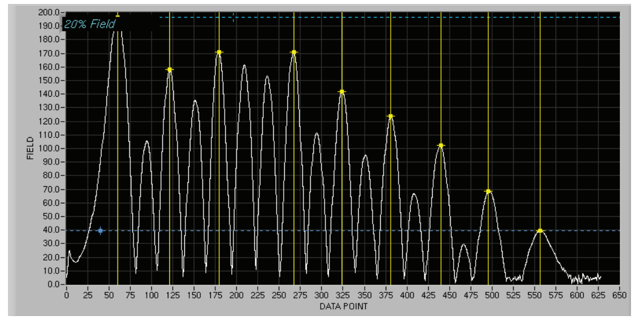

Figure 4a): Example for TM011 field distribution-asymmetrical cavity (maximum at first cell).

Figure 4a shows an example measurement for an asymmetrical cavity in good condition. The presented field distribution allows a good coupling to the HOM coupler and the TM011 HOM suppression will be sufficient.

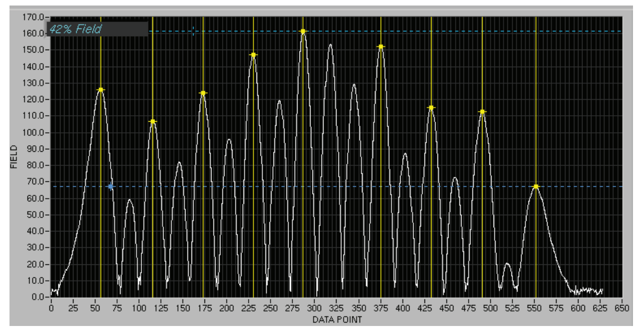

Figure 4b): Example for TM011 field distribution-symmetrical cavity (Maximum at middle cell).

Figure 4b shows an example measurement for a symmetrical TM011 mode distribution and therefore a pure coupling for the HOM coupler.

In summary about 1000 additional measurements not required by the European XFEL specifications, were done by CTMs at both companies. Herewith a good tool for further quality control was implemented to the cavity production. For future large SRF projects and cavity productions this might become a new standard.

SUMMARY

In the three years of European XFEL cavity production all targets related to implementation of HAZEMEMAs and CTMs were achieved or exceeded.

Not only the machines but also the service and repair concepts and the service and support teams from DESY and Fermilab have proven their ability for large industrial series productions at first rate.

An incredibly high number of measurements and tuning operations have been performed by the four supplied machines.

Within about 2500 operating days of the machines the availability was about 95%. The total 115 days (four machines, both companies) of machine down time did not cause any production stops. This was only possible with the close collaboration between both companies and DESY. During the entire production precious experience was gathered by companies and SRF community - which will also be used in future projects.

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