ANALYSIS OF THE TEST RATE FOR EUROPEAN XFEL SERIES CAVITIES

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Abstract

The main part of the superconducting European XFEL linear accelerator consists of 101 accelerator modules each containing eight RF-cavities. Before the installation to a module, all of these cavities will be tested at cryogenic temperatures in a vertical cryostat in the accelerator module test facility (AMTF) at DESY. This paper discusses the average vertical test rate at the present status. It should be 1 in the ideal case, but actually it's observed to be approximately 1.5. Classification and analysis concerning the reasons for this deviation are given as well as suggestions for a reduction of the test rate for future production cycles.

INTRODUCTION

The construction of the European XFEL linear collider is in full, swing. In total, 808 cavities have to be integrated into 101 cryogenic modules. To guarantee an adequate cavity shape, verify the performance and to set up the accelerator in an optimal way, all cavities have to take a comprehensive quality control in the Accelerator Module Test Facility (AMTF) by RF-testing at 2K. Not all cavities pass this test, so that multiple measurements for some are necessary. Since this kind of mass production is unique up to now, it is worth to classify the single tests and calculate the test rate (average tests per cavity). All tests of European XFEL series cavities up to the 31th of July 2015 were taken into account. Reference cavities (RCVs), used for the commissioning at the vendors site, are not included in the calculation, but a brief summary for them is also included. The actual status of the vertical test results is given in [1] and [2].

CAVITY TESTS AND TEST RATE

Vertical cold RF-tests of the superconducting 9-cell niobium cavities play an important role in the construction phase of the European XFEL. More than 800 cavities have to be tested in two vertical cryostats within 3 years. Test results are used for quality control of the performance and RF behavior and also for sorting the cavities into modules. To guarantee a sufficient test rate the cryostats are designed to install four cavities at a time (discussed in [3]). This helps to save worthwhile cool-down time, which is essential to bring the cavities to the module assembly area in time and hold the project schedule. An overview of the test set-up, as it is currently used in the AMTF is given in figure 1. A detailed description of the complete test sequence can be found in [4] and [5].

Figure 1: Vertical support structure for testing at AMTF.

The total number of vertical tests per month, without RCVs, is shown in figure 2. The average delivery rate per month appears to approximately 42 [2]. To get an overview of all cavity tests, the test rate as an expressive value was used. All cavities undergo at least one acceptance test. In order to understand better the evolution of retest rates during the production, we define an average monthly test rate as the average number of tests per cavity arriving in that given month (by definition ≥1). Note that the actual vertical tests can occur much later than the arrival date, especially for multiple retesting, but use of the arrival date gives a better indication of the actual production process at the companies. To date 1103 RF tests have been made on 741 cavities. This gives us an average test rate of 1.49 tests per cavity. Due to some vacuum problems (leaks, degasing, etc.) at low temperature, that were too serious for proceeding with the cool down cycle, the number of all cool downs is significantly higher at 1181 and leads to a cool down rate of 1.59. The trend of the test rate as defined above for both cases is given in figure 3. The reference date is the date of arrival at DESY and all tests, without RCVs, are counted in the following. Starting with a test rate around a value of 2 at the beginning of the series production, we have now stabilized at a value of around 1.2, established during a stable cavity delivery rate (see figure 2).

Especially in the beginning of 2014 and at the end of 2014/start 2015 we had a significant deviation between the test rate and the cool down rate, caused by a number of large cold leaks, which forced us to stop the cool down process before the RF-test could be performed. In these cases test results are not available and a transfer to the

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database did not take place. The drop in the rate at September 2014 is caused by some improvements at the manufacturer site, which were implemented during this time.

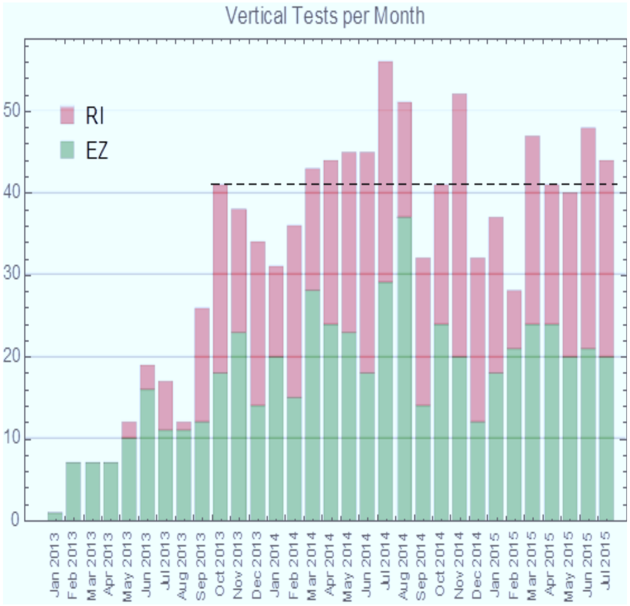

Figure 2: Vertical tests per month.

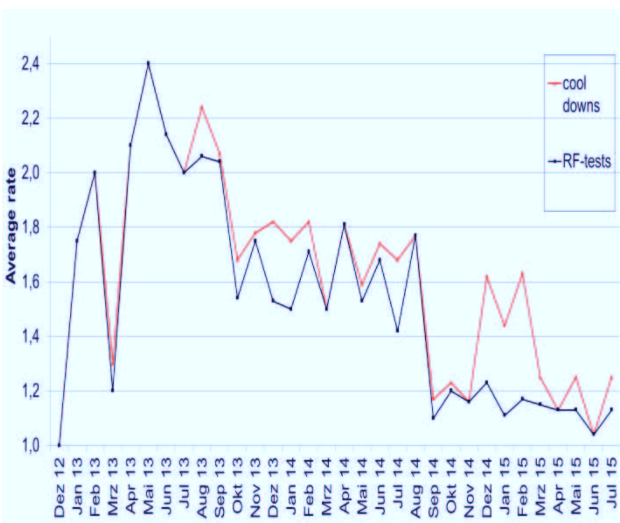

Figure 3: Development of the test rate.

CLASSIFICATION OF TESTS

For the reduction of the test rate and its fluctuation, it was helpful to classify the tests by assigning each test a "test flag" indicating the reason for the test. The test flag was implemented in the database for all cavity tests, so that detailed studies with different back grounds could be performed. For technical reasons the database handles real RF-tests only. Cool downs, that were stopped, before the RF-test was performed, are not available there. For this calculation it was an advantage to slightly modify the original test flags - used in the database - to other ones, to come to a simplified classification. All flags, used here, are shown in table 1.

Table 1: Test Flags

Test Flag	**Explanation**
As received	1st test with cavity as specified
Vacuum problems	Leaks occurred at cold temp. due to defect accessories or insufficient vacuum setup
RF problems	Insufficient RF-setup
Retreatment at DESY	Insufficient cavity performance without verifiable reason
Retreatment companies	Insufficient cavity performance related to manufacturer
Qualification infrastructure (companies)	Qualification of vendors infrastructure after shut down, after maintenance or after equipment failure
Problems at company	Intermediate additional test after welding, tuning problems, etc.
Other	Add tests on behalf of DESY after repair, transport, check of test stand/measurement, before tank integration or accidently
Defect accessories	Defect accessories (RF-functionality)
Scientific reasons	Verification of test results and scientific investigations (E_{max}, Q_0)
Retest after module assembly	Non conformities or accidents before or during module assembly

The distribution of all tests to the corresponding test flags / reasons is given in figure 4. If a cavity arrives as specified and passes the first test, it will be labeled with the flag "as received". In cases where fabrication flow was not as specified or did not pass the incoming inspection test, it will get a different flag. Consequently, it is possible that a cavity is accepted for a module without getting the flag "as received".

Figure 4 shows the distribution of all cavity tests already done. If we take into account, that the flag "as received" (63%) should be given in the ideal case to all cavities, we can conclude that 37% of all tests are related to some abnormalities during the cavities production or test phase. The flags "as received", "retreatment at DESY", "retreatment at companies" and "problems at company" are related to the cavity performance, while the other ones are related to the test infrastructure and the cavity accessories, which are the responsibility of DESY, IFJ-PAN and INFN. Splitting it, we get 82% of all tests are related to the manufacturer site and 18% of all tests are related to the test infrastructure (including cavity accessories).

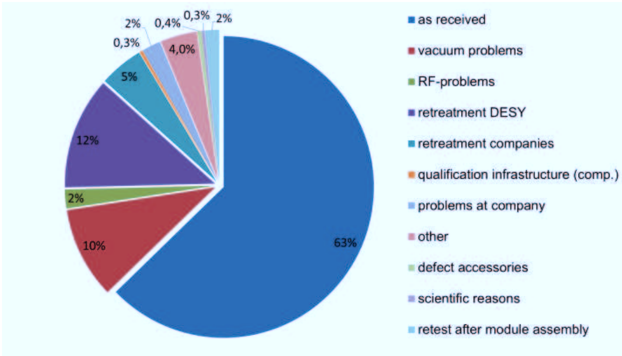

Figure 4: Classification of vertical tests.

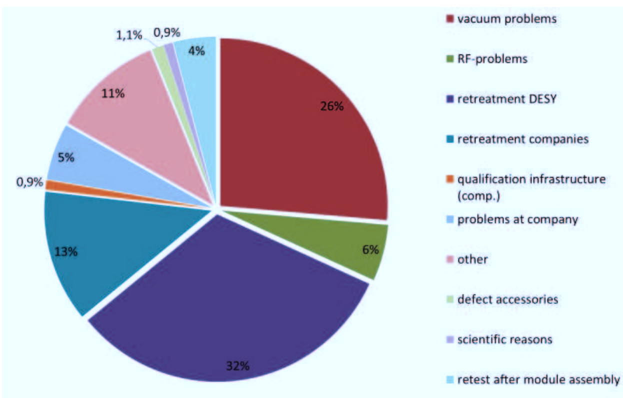

Figure 5: Test flags for multiple tested cavities.

The distribution of all additional tests, which are not the "as received" ones, is given in figure 5. The flags "retreatment at DESY" and "vacuum problems" are dominating, as was identified in the database at an early stage. A "retreatment at DESY" flag is usual assigned to a cavity which performs below acceptance level; i.e. when the gradient is below 20MV/m (26MV/m until May 2014, [6]). "Vacuum problems" are mostly related to the vacuum setup at the AMTF and defective cavity accessories. Most of the time was spent to fight against these two problems and considering figure 3 it was primarily successful. Referring the flags to the cavity performance or to difficulties on the customer site (cavity tests, module assembly) we get a ratio of 50:50. At the customer site 4% of all additional tests are related to insufficient incoming inspections and problems at the module assembly.

COMMISSIONING PHASE AT VENDORS

Some additional cavities were ordered at the project start-up, called reference cavities (RCVs), used for the commissioning at the manufacturer site. A complex process was performed, to qualify the several infrastructures at the companies, like EP, BCP, HPR, slow venting, etc. before release them to start with the surface treatments of the series production. RCV cavities were mechanically fabricated at the companies, fully treated and tested at DESY, and finally gave back to the companies for the qualification process. The RCVs were treated with a respective treatment system and tested again. In case that the measurement of a new test at DESY was within the specification, the system was accepted. The complete procedure is given in [7]. The RCVs are used for further qualification processes i. e. after maintenance, machine failure or operating error during treatment process.

In total 36 tests were done for the qualification of the vendors infrastructure, but not all of them were done with a RCV. At a later stage of the series production sometimes a series cavity was used to minimize the time for the requalification. With a value of < 1% this number is very small (see figure 5).

CONCLUSION

The development of the test rate over the period of the cavity production was presented and a classification procedure for all tests is described. The tests can be related to the cavity fabrication (vendor) or to the handling at DESY and module assembly area. The main reasons for additional cavity retests are "Retreatments" and "vacuum problems". A short overview of cavity tests during the commissioning phase at the vendors has also been presented.

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