

# UPGRADE OF THE ARCING SUPPRESSION SYSTEM FOR THE WAVEGUIDES IN THE EUROPEAN XFEL

M. Bousonville<sup>†</sup>, F. Mantas, S. Wiesenberg, P. Hülsmann, C. Christou  
Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany

## Abstract

When planning the European XFEL, the decision was made to avoid using SF<sub>6</sub> in the waveguide systems. Instead, air was used at slight to high overpressure. When slight overpressure is used, the air is also in motion. The air flow travels from the RF source towards the cavities and is released again before the coupler. This ensures that, in our non-gas-tight waveguide system, the air quality in the waveguides corresponds to the air quality supplied by the compressor. Particles and ionised air that could promote arcing are blown out. Originally, the air pressure was generated by local compressors and the air used came from the ambient atmosphere. Now, the accelerator's central compressed air system is utilised. Locally, only the newly developed controls for air pressure and flow remain. The advantage of the central compressed air supply lies in the significantly better air quality and greater operational reliability.

## INTRODUCTION

In the past, SF<sub>6</sub> was used in the FLASH accelerator for the 1.3 GHz systems to prevent arcing. However, the use of SF<sub>6</sub> presents a number of problems. It is an inert asphyxiant that can decay into toxic products, difficult to handle and a highly environmentally harmful gas. For this reason, it was decided as part of the planning for the European XFEL that the new RF stations would be operated without SF<sub>6</sub> [1].

The XFEL operates using very long RF pulses (1.4 ms / 10 Hz). The klystrons used can deliver up to 10 MW of RF power. To prevent the RF power in the output windows from becoming too high, the output power is split between two RF windows, so that a maximum of 5 MW is present in each window. The power from both outputs is recombined only at the gun, so that in operation a maximum of 6.5 MW occurs in a single waveguide. For all the other 25 klystrons of the XFEL, which drive the superconducting accelerator modules, the power is not recombined. Each klystron feeds 4 accelerator modules with a total of 32 cavities (Fig. 1). Two of these accelerator modules are connected to each of the klystrons' two RF outputs. The klystrons deliver a maximum of 6.6 MW during operation. Consequently, a maximum of 3.3 MW is present in the waveguides here.

The waveguides are filled with air. To supply the gun with the high RF power of 6.5 MW via one waveguide, an overpressure of 2 bar was originally used [2]. According to

Paschen's law [3], this measure significantly increases the breakdown strength. The gun waveguide distribution has since been modified, and the RF power is now fed to the gun via two air-vacuum windows, so that each window only has to transmit half the RF power and the overpressure could be reduced.

Higher internal pressure is one way of decreasing the probability of breakdown in air-filled waveguides. In this case, however, special waveguide components are required that can withstand these pressures and are sufficiently gas-tight. This is a very complex process and has therefore only been envisaged for the end of the gun waveguide distribution system.

## AIRFLOW IN THE WAVEGUIDES

Another way of decreasing the probability of breakdown in air-filled waveguides is to use air of a high degree of purity. Generally speaking, impurities in the air promote breakdown in waveguides. The air should therefore be as pure as possible. We achieve this by injecting air of a known quality (Fig. 1). The air is fed into both klystron waveguide arms. The tree-like structure of the waveguide distribution allows the air to follow the same path as the RF wave and to split symmetrically towards the cavity couplers. At the end of each waveguide branch, just before the coupler, there is an outlet valve through which the compressed air can escape. The air is typically injected at 0.05 bar overpressure, resulting in an air flow of 10 to 30 l/min. These varying air flow rates result from the waveguide distribution being more or less airtight, as standard air waveguides are used which are not gas-tight. This system ensures that the air quality in the waveguides is identical to that of the injected air. This allows control over the air quality in the waveguides. If the air were to stagnate rather than flow, ionised air resulting from arcing would not be dissipated and would cause subsequent problems – namely, the promotion of further arcing.

## AIR QUALITY UPGRADE

Originally, the air used was simply drawn from the ambient atmosphere in the accelerator tunnel. One compressor per station drew in air from the surrounding environment and blew it into the waveguide arms. It should be noted, however, that air – or compressed air – always contains particles of dirt. These include, above all, solid particles, water and oil [4]. As there is a significant level of dust in the XFEL's accelerator tunnel, the air being blown in was obviously contaminated with particles.

<sup>†</sup>michael.bousonville@desy.de

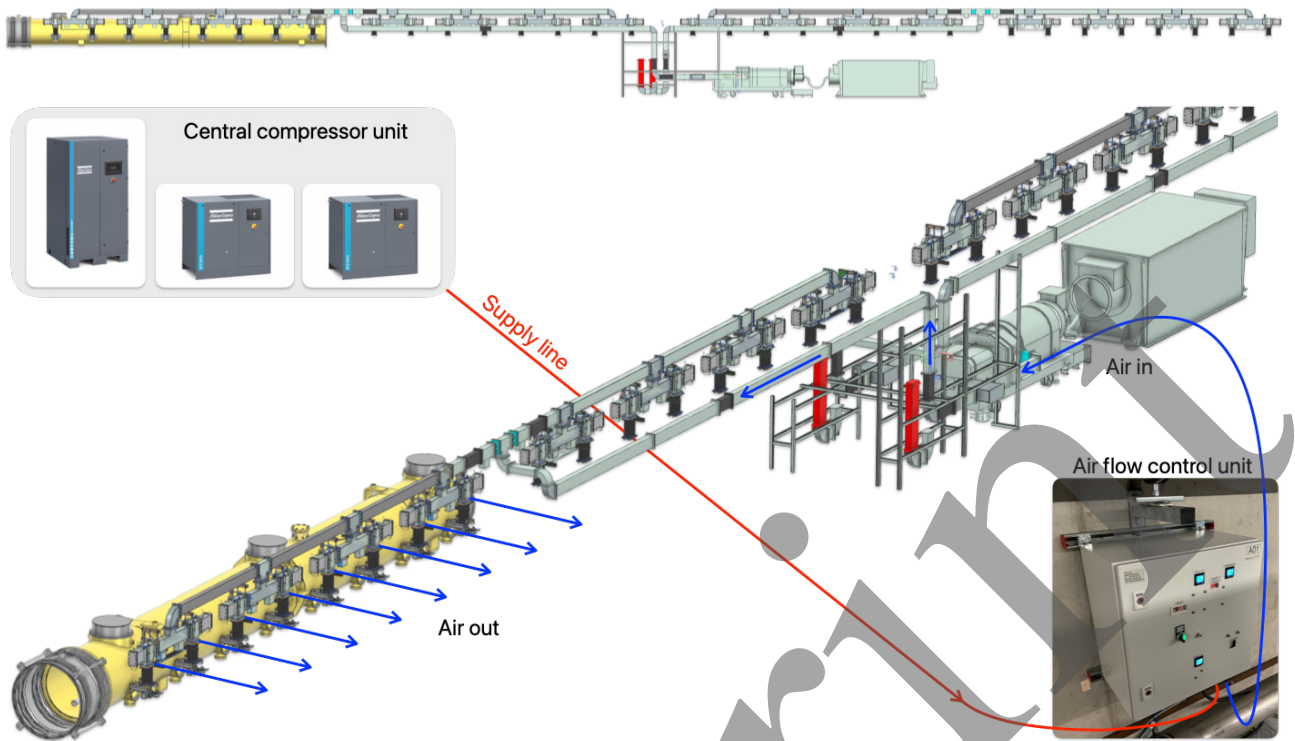


Figure 1: Air flow in the waveguide distribution system. The air is forced into both klystron arms and released just before the 32-cavity couplers. For the sake of clarity, the diagram shows only the air flow from one klystron output to one of the four accelerator modules.

This led to the idea of switching from decentralised compressed air generation to a centralised system. A central compressor was already in place, and it still had sufficient capacity for our 26 RF stations. The compressor delivers very good air quality, meeting Class 2 standards in accordance with ISO 8573-1:2010.

ISO 8573-1:2010 is a set of international standards that defines the quality and purity of compressed air. The air is classified by specifying a maximum permissible concentration of contaminants that may be present in the air. These contaminants include particles, water and oil. Each class has a defined maximum limit for these three substances. The classes range from 0 to 9 – plus class X. The required purity decreases as the class number increases. Class 0 can be specified by the equipment user themselves, but must be subject to stricter requirements than Class 1 [4]. Below, we discuss some key properties of the air used in accordance with Class 2 of ISO 8573-1:2010.

### Particles

The number of particles in the air is so low that, rather than their mass concentration in  $\text{mg}/\text{m}^3$ , the particle count for different particle sizes per  $\text{m}^3$  is specified. For our Class 2 compressor, this means that for the particle sizes

0.1 – 0.5 $\mu\text{m}$	$\leq 400,000$ particles/ $\text{m}^3$
0.5 – 1 $\mu\text{m}$	$\leq 60,000$ particles/ $\text{m}^3$
1 – 5 $\mu\text{m}$	$\leq 100$ particles/ $\text{m}^3$

are present. As the XFEL tunnel consists of exposed concrete surfaces, there is a significant amount of dust inside

the tunnel. Consequently, the low particle count from our central compressor represents a major improvement in quality.

### Humidity

The air is so dry that, instead of specifying the water content in  $\text{g}/\text{m}^3$ , the vapour pressure dew point is given as  $-40^\circ\text{C}$ . Previously, we had a relative humidity of 40 to 60% in the waveguides; now it is 0 to 3%. The humidity from the central compressor cannot be measured by our sensors. We therefore assume that the values we have measured at the outlet of the compressed air and flow control system are due to leaks in the air flow control units. As the compressed air temperature is between 25 and  $30^\circ\text{C}$  and the external temperature of the waveguides is always above  $20^\circ\text{C}$  during operation, there is no risk of condensation forming in the waveguides.

### Oil

The total concentration of oil (liquid, aerosol, mist) is also negligible at  $0.1 \text{ mg}/\text{m}^3$ . We assume that there was previously a much higher concentration of oil in the air, but were unable to measure it.

## AIR FLOW CONTROL UNIT

There is one air flow control unit per RF station. The central compressor supplies all air flow control units with 6 bar via a compressed air distribution system (Fig. 1). The same applies to the air pressure control units for the gun. Figure 2 shows an air flow control unit.

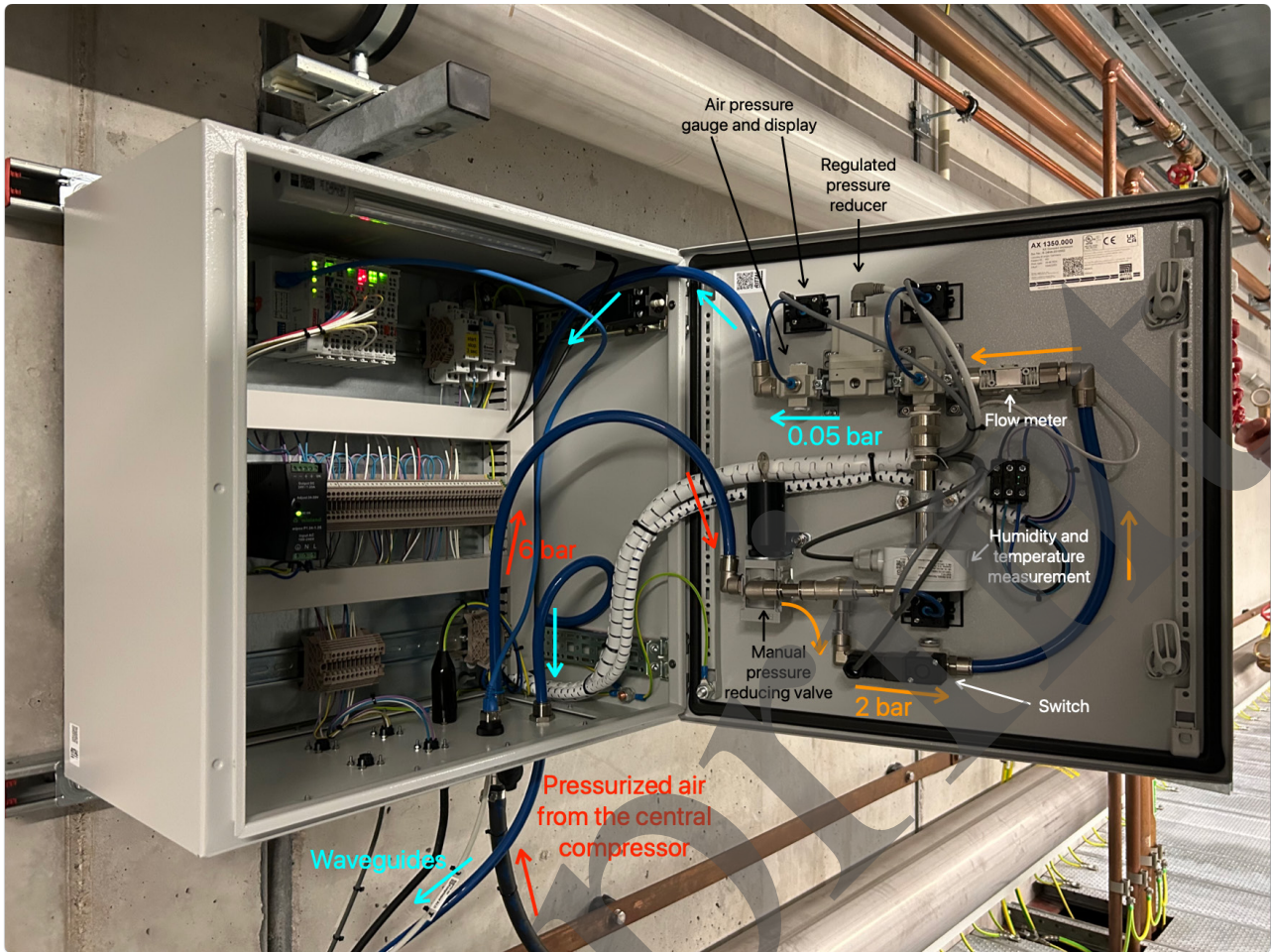


Figure 2: Air flow control unit. It regulates the pressure at which air is forced into the waveguides. Typical air pressure values are shown in the figure.

Air from the central compressor is fed to the air flow control unit at a pressure of 6 bar. In the first stage, this pressure is reduced to 2 bar via a manual pressure-regulating valve. The pressure is measured and monitored downstream of the pressure-regulating valve. This is followed by a switch that can be used to shut off the compressed air supply to the waveguide distribution system. This component is followed by a flow, humidity and temperature sensor. A further pressure regulating valve, this time electronically controlled, follows. This valve is used to set and maintain a constant pressure at which the air is forced into the waveguide system. Typically, 0.05 bar. The set values for the manually set inlet pressure (approx. 2 bar) and the pressure for the waveguide supply (approx. 0.05 bar) are displayed on the front panel. In addition, pressure readings at three measuring points in the system and the air flow are shown.

### IMPROVEMENTS

The following aspects have improved significantly as a result of the upgrade:

1. Air quality  $\Rightarrow$  Prevention of arcing improved
2. Reduction in downtime
3. Maintenance effort and costs reduced

Air quality has already been discussed in detail. The reduction in downtime is due to the fact that the decentralised compressors were not as reliable as the central compressor. In the past, failures of the decentralised compressors led to downtime for the entire accelerator. The central compressor is operated so reliably by an infrastructure team at DESY that we have not experienced a single outage since the first five Air Flow Systems were switched over to the central compressed air supply in the summer of 2022. Consequently, maintenance effort and costs are lower. It is no longer necessary to maintain 26 decentralised compressors, but only a single central unit.

### SUMMARY

The upgrade was a complete success. Since its implementation, no further arcing has occurred in the waveguide distribution system. The uptime of the Air Flow System has been significantly increased, whilst maintenance effort and costs have been reduced.

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