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Precision

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Navdeep Mehay, Machine Control and Protection Group Leader at MAST-U replies:

Background:

Fusion Power is generated by harnessing the energy released by replicating the fusion processes that happen within stars e.g. The Sun. The Sun uses hydrogen as a fuel and the core temperature of our Sun is estimated to be 15million°C, however the fusion rate for hydrogen is very slow, in order to generate power by the fusion within a machine on earth, we need to use a different fuel based on heavy hydrogen called Deuterium and Tritium, which requires plasma temperature in the region of 100million°C. This is achieved in a fusion reactor or machine commonly known as a tokamak (Russian word токамак).

Culham Centre for Fusion Energy

One of the biggest challenges in Fusion machines is to find a way to dissipate hot plasma exhaust without damaging the surface of the divertor. Science communities around the world are working towards overcoming such challenges and helping to convert theory into practice for efficient future power generation. UK has its own "MAST-Upgrade" machine at Culham Science Centre which is going through commissioning following major upgrades to enable scientists to carry out experiments into how to handle this heat. However, machines like original MAST and JET at CCFE have already produced excellent results for the fusion community.

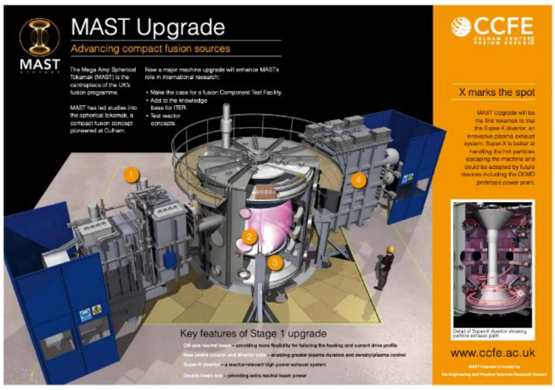

Figure 1: MAST-U upgrade plan

Plasma measurements

To measure the temperature within plasma we use scientific techniques like Thomson Scattering which, by observing spread of a scattered light wavelength, can measure speed of the particles and hence calculate temperature using their velocity distribution. The intensity of scattered light can also give us the information on the electron density. In addition, over 700 Langmuir probes at various locations will give us electron temperature, electron density, and electric potential of the plasma.

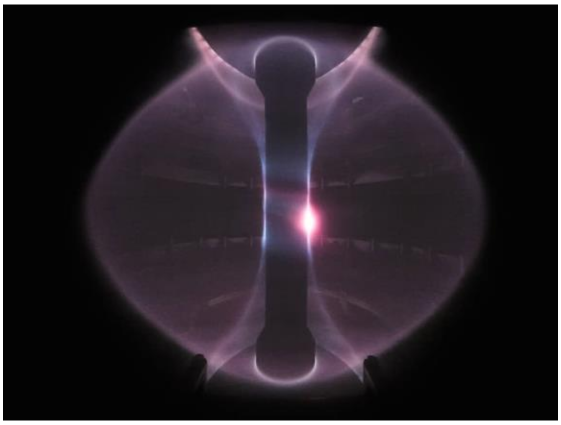

Figure 2: Plasma test inside the original MAST machine

Engineering Challenges:

Now let's talk about the real challenges to bring this science into reality.
(*I hope no scientists are reading this!)*

During experiments on original MAST machine, the plasma lasted for around 0.5 seconds and after upgrades it will last for 2-5 seconds on MAST-U which gives us enough time to accurately measure various parameters including shape of the plasma. Before we start measuring millions of °C, let us discuss protecting our measuring instruments. The magnetic field generated by coils, which surround the vessel, help shape the plasma and hold it stable within the tokamak without touching the inside wall. This makes machine body temperature measurements easier by using K- or T-type thermocouples.

And more…

Now, once we have active equipment like reciprocating probe connected to the machine, our challenge is to expose it to the extreme high temperatures within the machine for the shortest possible duration during the pulse. This is achieved by using precisely controlled gate valves to operate and allow the equipment to enter while maintaining vacuum inside the vessel. Also, it becomes imperative to capture every milli second of the activity on every shot. Engineers at MAST-U have designed and implemented an FPGA based Fast Timers control system which provides an operational window and ensures timing accuracy better than ±0.5ms over a 20s period. Again, thanks to FPGAs, Real Time Protection (RTP) control system is designed to detect any coil fault and kill the power to coils within 600µseconds to protect against flashover/sudden high loads.

A closed loop z-control system is in development which will control vertical movement of very light weight and jelly-like plasma in real time. But these discussions are for another day.