Actively circulated liquid metal divertor (ACLMD)

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The use of actively circulated liquid metal is proposed to facilitate heat handling of the divertor, which is a very serious and challenging issue in fusion reactors, especially since fusion power in a DEMO reactor will be several times the fusion power of ITER and yet the reactor size will be similar. Furthermore, copper cannot be used for cooling tubes, and reduced activation alloys such as F82H will thus be the structural material even as its heat conductivity is substantially lower than that of copper.

The present proposal is to fill the lower part of the vacuum vessel with a liquid metal like Ga, Sn with a low melting point and low chemical activity. The divertor modules, toroidally segmented like conventional divertor and equipped with electrodes and cooling tubes, are immersed in the liquid metal. The electrodes, placed in the middle of the liquid metal, can be biased positively or negatively with respect to the module. The $j \times B$ force due to the current between the electrodes and the module actively drives a poloidal motion of the liquid metal (~0.3 m/s) in such a way that the temperature rise at the separatrix hit point is kept at an acceptable level (~200 degree C). As the rotation speed builds up, the current in the liquid metal is reduced due to the $v \times B$ electromotive force, often referred to as MHD drag. After the liquid metal rotation reaches a steady state, the electric field in the liquid metal is almost completely compensated for by the $v \times B$ electromotive force which reduces the current to a very small value.

The poloidal motion of the liquid will distribute the heat to a wide area, greatly enhancing the heat handling capability of the divertor. If the poloidal motion of the liquid metal distributes the heat load uniformly over the inner wall of the divertor module, the power density will be ~1.3 MW/m², which is easily removable with conventional technology. To avoid excessive current during the ramp-up, the voltage and the rotation should be ramped up rather slowly (e.g. in 1 minute). Insulating plates should be inserted between divertor modules to avoid short circuit along the field line.

Our estimate suggests that only a few volt will suffice as electrode voltage and the maximum current to an electrode will be ~10 A for the case of DEMO. ACLMD also facilitates the recovery from unmitigated disruption, another serious issue for burning plasma experiments with tungsten divertor, and eliminates the erosion problem of the divertor. A laboratory-scale setup for proof-of-principle experiments is being put together at NIFS and the results will be reported at the conference.