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ABSTRACT.

The conventional JET ICRH antenna matching system cannot respond to large and rapid load variations induced by the ELMs. Unacceptably large bursts of reflected power occur at the generators, severely limiting the ability to deliver RF power to ELMy plasmas. A wideband matching system based on prematching sliding impedances and fast frequency control is under commissioning on one of the antenna arrays. When suitably configured, the new system, which operates in 4 frequency bands inside the JET plant range, should strongly reduce the ELM-induced power reflection by rapid adjustments of generator frequency. The paper reports recent progress achieved in its commissioning. Successful operation of the fast frequency control loop has been demonstrated during ELMs, and work is underway to bring the system to full operation.

1. INTRODUCTION

The Edge-Localized Modes (ELMs) induce large and rapid impedance variations on the JET A2 ICRF antennae. The conventional RF matching system, based on stubs and line stretchers, cannot respond on such a short timescale (ELM rise: 50 to 100μs; ELM fall: a few ms). Unacceptably large bursts of reflected power thereby occur at the generators, triggering protective RF power trips and severely limiting the ability to deliver power reliably to ELMy plasmas. A wideband matching system has been developed at JET to address this crucial problem [1-5]. It consists of: (1) Adjustable prematching elements, the Sliding Impedances ('SLIMPs', Fig.1), inserted in series in the transmission lines feeding the four straps of the A2 array. Each SLIMP (Fig.2) includes a high impedance section (~105 ohm) of adjustable length (0.4 to 4.4m, normally operating close to quarter wave), in series between two fixed-length 24 ohm sleeves adjustable by 1m in position; (2) An upgade of the generator frequency control to allow faster variations (up to 300kHz in 300ms); (3) Specific algorithms and circuits developed to control the new system. Two of the four ICRF arrays (C and D) are currently fitted with SLIMPs: array C, the prototype system, is also equipped with full control electronics; array D has its SLIMPs in fixed "parked" position (24ohm sleeves fully up, high impedance section fully down).

We report on the work carried out during the four JET experimental campaigns of 2000 and 2001.

2. PRINCIPLE OF WIDEBAND OPERATION

Each SLIMP must be configured to achieve near-adaptation of its antenna transmission line (ATL, ~16m to strap short circuit) to the corresponding main transmission line (MTL,~70m), with typical ELM-free ATL SWR ~15 and MTL SWR ~ 4. In such a configuration, the variations of ATL SWR (resulting from ELMs) are converted into variations of the wave reflection coefficient phase on the MTL. The MTL SWR is close to a minimum and relatively unaffected. Moderate variations of the RF frequency (≤300kHz) compensate these MTL phase variations and strongly reduce the generator SWR. These frequency adjustments are much faster (300kHz in 300ms) than any mechanical element (requiring ~1s). This near-adaptation of the MTL is a compromise between low MTL SWR and moderate frequency excursions. Wideband operation is possible around 4 frequencies (28, 36, 44 and 52MHz) inside the JET plant band (23 to 57MHz). Some advantages of such a system over 'ELM dump' systems (such as based on 3dB hybrids [6]) are (1) real-time adaptation, yielding reduced return power loss and increased average coupled power during frequent ELMs; (2) preservation of the arbitrary phasing capability and the independence of the JET A2 antennae. An additional benefit of pre-adaptation with SLIMPs is the strong reduction of MTL ohmic losses. The drawbacks are (1) a highly sensitive system, requiring very accurate mechanical positioning (≤1cm for ATL sleeve), accurate RF measurements, and a robust frequency control algorithm; (2) the frequency deviations must control four lines simultaneously, so high consistency of settings is required over each A2 array, despite differences of coupling resistance between straps.

3. COMMISSIONING ON PLASMA

In addition to a reference (ELM-free) adapted antenna load, wideband matching seeks to achieve low reflection over a load-frequency trajectory [5]. There are two aspects to the control: the system must first be accurately positioned in a favourable configuration, with reference electrical settings established by modelling; once this has been achieved, frequency deviations must track the low reflection trajectory during the ELM-induced load variations. The respective control algorithms are based on signals exclusively derived from RF measurements. This formulation avoids using an electro-mechanical model of the SLIMP in its control system; the only mechanical informations required are the direction of motion of each element in response to its error signal. Shot-to-shot improvements to the reference configuration are estimated from the error signals. With current practice, some 3 shots at the target ELM-free coupling are necessary, with steady coupling conditions best provided by feedback control of the plasma position. The resulting configuration is assessed at low power by means of RF frequency sweeps (max.±300kHz at a 5Hz rate), combined with slow changes of antenna coupling produced by radial displacement of the plasma. It has been possible to achieve fairly similar configurations simultaneously on the 4 straps. Good agreement is obtained between these data and simulations of the matching circuit, provided sufficient detail is included in the antenna representation. An important dependence of the antenna equivalent length on plasma conditions has indeed been observed at fixed RF frequency and array phasing. This requires frequent re-tuning of mechanical settings, a strong incentive to optimize the presetting procedure and fully commission automatic adjustments. Improved modelling and low power measurements made on a spare SLIMP will help achieve this. Fast frequency tracking is implemented as a linear approximation (with limits) of the optimal load-frequency characteristic [3, 5]. The frequency error signal, updated every 2μs, is computed either from measurements on a single line or averages over one pair. Troubleshooting and initial closed-loop operation of the frequency feedback has first been carried out in "slow motion", using plasma displacements to modify the antenna coupling. Our main result to date is the successful commissioning of the frequency feedback loop during ELMs, where the fast acquisition of RF signals at a 16ms rate is an essential analysis tool. The left part of Figure 2 shows the response of the frequency to a series of ELMs, with a coupling resistance Rc (=30 ohm/swr) typically varying between 2 and 8 ohm and large variations of the ATL reflection phase. The frequency deviation correctly drives the error signal to zero, but its reponse is too slow. The right part of the same figure shows improved response to an ELM after the feedback loop integrator gain had been increased by a factor of 8. Note that these tests have been carried out at powers of order 100kW. Commissioning on ELMs has not yet demonstrated satisfactory overall operation (the reference settings must be further improved first). Antenna and line frequency dispersion over the 300kHz deviations must be taken into account to assess and achieve optimum performance. A first attempt has been made to incorporate these effects by modification of the frequency error signal. The control algorithm must now be optimized on the basis of latest RF data with ELMs and accumulated operational experience. The new system puts an unprecedented demand on the quality of RF measurements, and the accuracy of the measurement chain is under detailed assessment.

CONCLUSIONS

Important progress has been achieved in the commissioning of the JET ICRF wideband matching system, with many hardware problems identified and cured. The most significant result is the demonstration of successful operation of the fast frequency feedback loop during ELMs. A successful operation of the system with low generator reflection and improved power delivery to an ELMy plasma has however not yet been established, and optimization is continuing to bring it to best possible performance. Given the complexity of its operation, the future of the wideband SLIMP configuration is currently being reviewed. Complementary measures to improve ELM resilience and alternative SLIMP operating modes are also under investigation.

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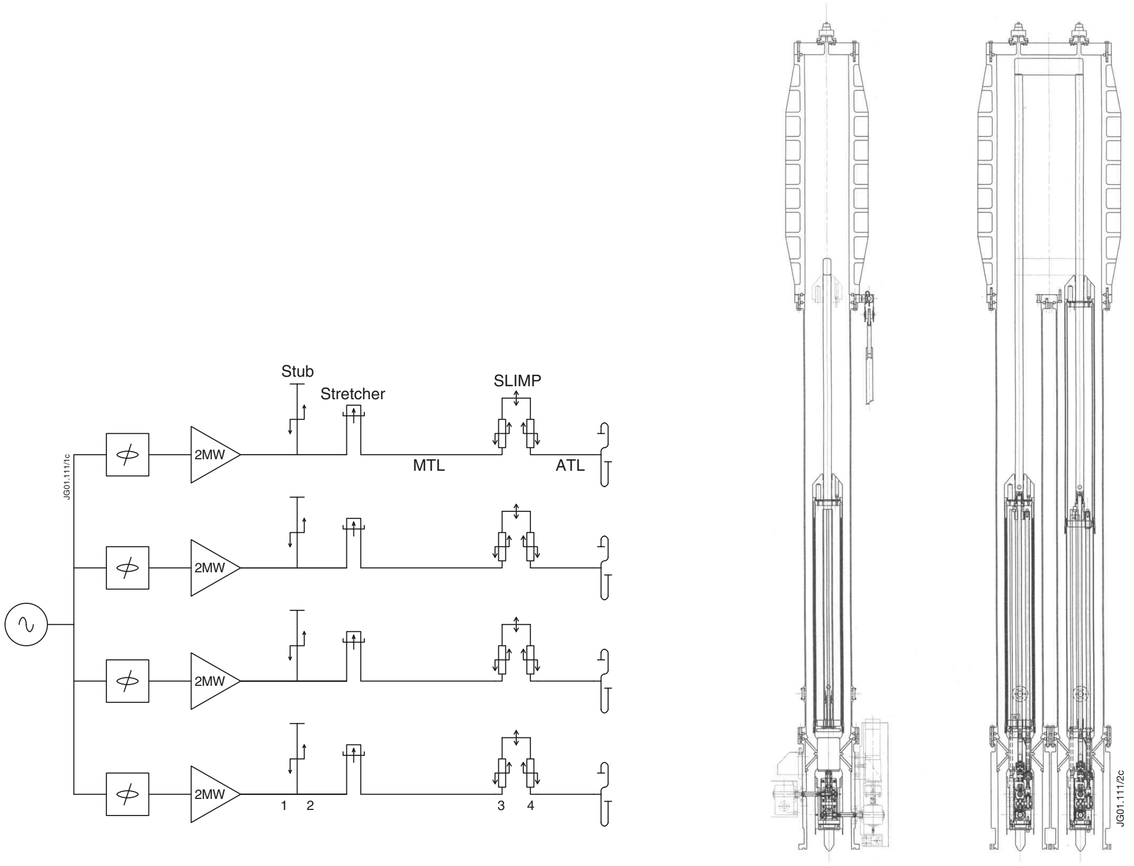

FIGURE 1: Left: transmission and matching system of a JET A2 ICRF antenna equipped with sliding impedances. Right: side and front views of a SLIMP.

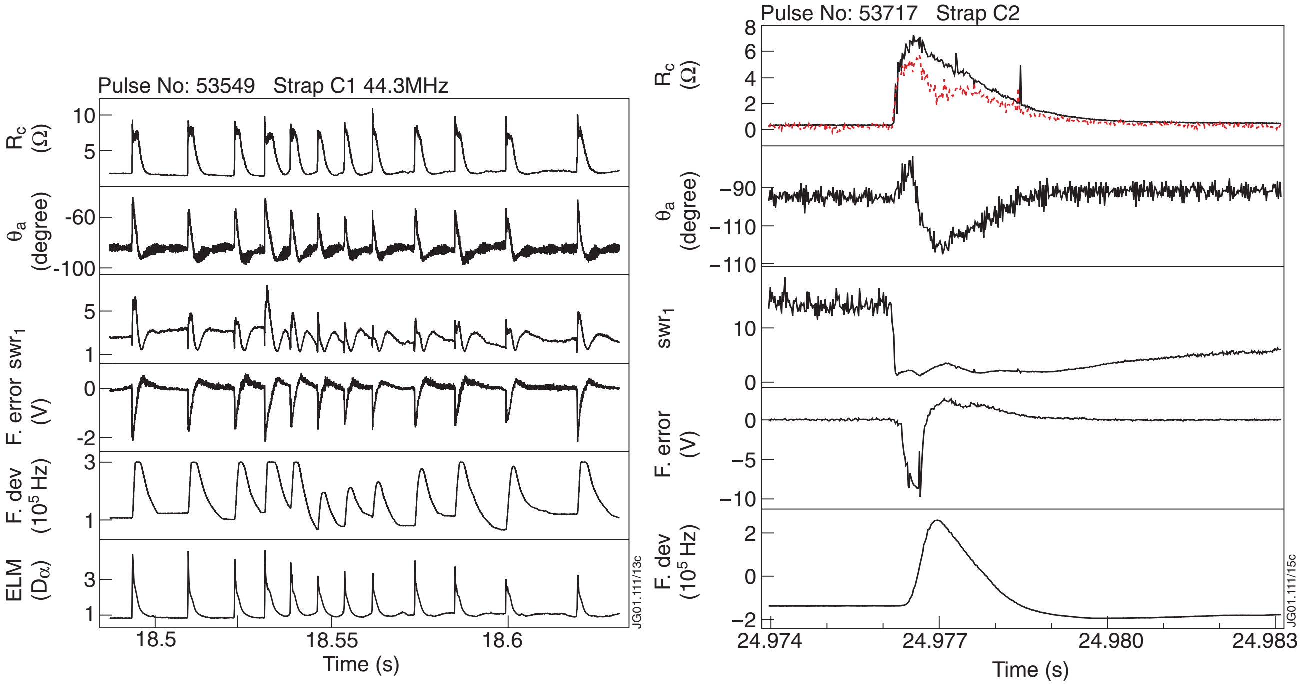

FIGURE 2: Closed-loop operation during ELMs, showing coupling resistance, ATL reflection coefficient phase, generator swr, and frequency error signal driven toward 0 by frequency deviations. (N.B. left: ELM-free adaptation not optimized). Right: improved response to an ELM after increasing the frequency control loop integrator gain (non-dedicated test pulse, extremely low ELM-free coupling).