Assessment of the effect of vibration applied to the ITER FOCS in the cryostat bridge

S. -M. Kim,[1] P. Dandu,[1] A. Gusarov[2], A. Danisi[3], G. Vayakis[3], and M. Wuilpart[1]

[1] University of Mons, Dept. of electromagnetism, Boulevard Dolez 31, Mons, Belgium
[2] SCK-CEN Belgian Nuclear Research Center, Boeretang 200, Mol, Belgium
[3] ITER Organization, Route de Vinon-sur-Verdon CS90 046, 13067, St Paul Lez Durance, Cedex, France

Structural vibration can occur during the plasma operation in ITER, and in this paper, the effect of this vibration on FOCS was analyzed. The structure of interest was Cryostat bridge which is a part of path that delivering light from control room to the sensing region. A miniaturized structural sample was prepared with a shaker to measure the effect of vibration. A fiber was inserted through the miniature setup, and output polarization change of fiber was monitored during the vibration environment. From the measurement data, the entire structure can be modeled with Jones matrix calculation. With this full model, the vibration effect of the FOCS can be estimated with Lo-Bi and Hi-Bi spun fiber. As a result, it was shown that using lo-bi spun fiber is desirable to satisfy the ITER requirement.

Introduction

Fiber-optic current sensor (FOCS) will play an important role in ITER for machine protection. FOCS measures the plasma current by monitoring the rotating polarization plane due to the Faraday effect [1]. The optical fiber will deliver the optical signal from the diagnostic building to the vacuum vessel through the cryostat bridge, which has possible vibrations in operation. It is known that FOCS with Faraday Mirror can compensate for the vibration effect of fiber, but it does not work perfectly when the nonreciprocal Faraday effect coexists [2].

To estimate the vibration effect on the whole bridge structure through experiments on small parts, we selected a part that can be optically modeled. In the bridge structure, since the optical fiber will be installed in a metal tube made of a helical shape of 5 turns, 1-turn of helix metal tube was prepared as a single model. Vibrations of worst-case scenario were applied on the single model and polarization state of light passing through this fiber was monitored. By using Jones matrix, the optical modeling for the single model can be extended to the entire model will be installed in the bridge structure (5-turns of helix). From this model, the FOCS accuracy can be estimated with possible vibrations. In addition, the comparison between the Lo-bi and Hi-bi spun fiber was also discussed. As a result, when the FOCS using a Lo-bi spun fiber, the measurement accuracy is satisfied the ITER specifications.

FOCS structure installed in ITER and possible vibration

In ITER, most of the optical components of the FOCS system are installed in the cubicle area, and only optical fibers are connected to the vacuum vessel (VV) area and installed around the VV. Between the cubicle area and the vacuum vessel, there is a vibration potential area in the vicinity of the cryostat bridge as shown in the Figure 1.

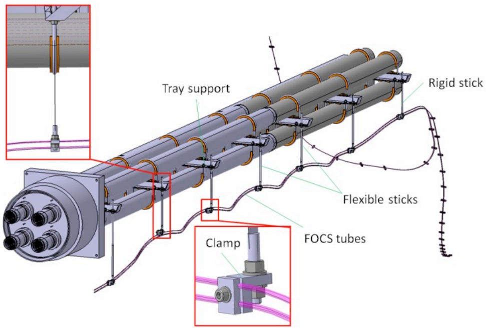


Figure 1 Overview of the FOCS integration in ITER.

From this design, ITER conducted a structural analysis for the problematic situations such as seismic event (SL) and vertical displacement event (VDE). Table .1 shows the result of simulation which can be the worst-case scenario [3].

Table 1 Simulation result for acceleration and deformation component from accidental events [3].

		VDEII	VDEIII	SL2
Full	Total deformation [mm]	16	14.85	5.18
	Acceleration X [m/s²]	37.85	35.86	6.67
	Acceleration Y [m/s²]	76.81	69.06	19.5
	Acceleration Z [m/s²]	24.97	25.68	25.02

To see the vibration effect in the worst-case scenario, VDEII case was selected with total 16 mm of deformation and 76.81 m/s^2 of acceleration in the y-direction.

Measurement setup for vibration effect on the fiber

A polarization state measurement setup was prepared to see the vibration effect on the fiber as shown in Figure 2. A laser was prepared to launch the light through the spun fiber and a SOP controller was connected before the spun fiber to control the input polarization state. The spun fiber was inserted in a stainless-steel metal tube which has 2-turns of helical shape. In the middle point of the 1st turn of the helix, a shaker was placed to apply the vibration. A signal generator was connected to the shaker for controlling the vibration parameter discussed in the previous section. The relation between the input signal and the acceleration was monitored by using an acceleration sensor and an oscilloscope. The output polarization state was then monitored by a polarimeter (polarization analyzer) while the vibration was applied to the spun fiber.

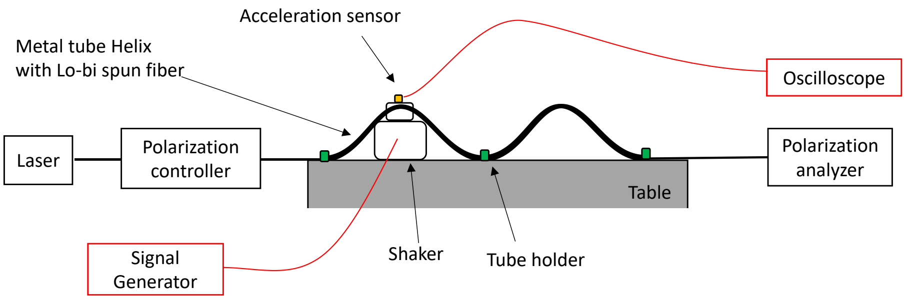
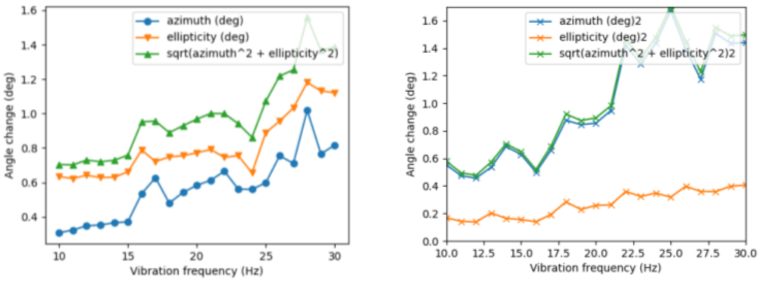


Figure 2 Vibration effect measurement setup

Measurement result from the vibration experiment

The applied vibration was controlled by the function generator for having constant displacement with different frequency from 10 Hz to 30 Hz. When the vibration is applied on the fiber, the polarization analyzer shows the measured state of polarization (SOP) as a point on the Poincare sphere. As the device has high data acquisition rate (10kHz), the point is spread according to the vibration effect. By measuring the change of SOP, the vibration effect can be estimated. The measured SOP change is calculated as angle changes in Poincare sphere, as shown in Figure 5 (a). From this experiment, we could estimate that the vibration applied on the single turn will affect the SOP change of 1.6 deg. Another vibration experiment was then performed with Hi-bi spun fiber and the result was shown in Figure 5(b). The SOP changes in Hi-bi spun fiber was 1.65 deg which is similar to the Lo-bi spun fiber cases.



(a) (b)

Figure 3 SOP changes by vibration effect with (a) Lo-bi spun fiber, (b) Hi-bi spun fiber.

Optical simulation for vibration effect on the FOCS

Based on the experiment, we performed simulations using Jones matrix formalism with a method similar to that presented in a previous paper [4]. The spun fiber (Jones matrix M_{Fiber}) can be modeled as in [2] and the vibration effect can be taken into account by inserting in the middle of the spun fiber model a vibration Jones matrix (M_{Vib}) which induces a SOP changes having the same properties as in the experiment. Multiple simulations need to be performed by setting the vibration matrix parameters to arbitrary values within the range of experimental values. The birefringence axis angle (θ) of the inserted vibration matrix (M_{vib}) is unknown but within the range of [-π/2, π/2]. For linear (ϕ) and circular birefringence (Θ), we set (ϕ, Θ) ∈ [-1°, 1°] which is slightly larger than the measurement range (±0.8°). The single structure can be modelled as $M_{Fiber}M_{Vib}(\theta,\Theta,\phi)M_{Fiber}$. As the number of total turns of the helix-shape is 5, the entire model can be expressed by multiplying the helical model of 1-turn in multiple times. The FOCS measurements can then be estimated with a Jones matrix simulation for the extended structure as shown in Figure 7. Since the input light is reflected by the FM, each vibration matrix propagates forward and backward, affecting twice the optical beam. The measurement of the rotation angle induced by the plasma current is simulated by applying this structure.

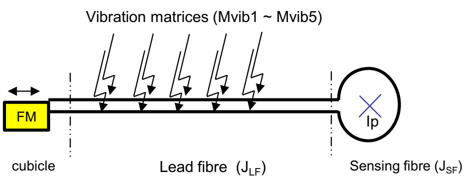


Figure 4 A simulation model of FOCS with 5-turn of helix with vibration matrix.

Multiple simulations were performed for the random vibration matrices defined before. The spun fiber used in this simulation was a Lo-bi fiber which have intrinsic beat length (Lb) of 1 m and spin period (Sp) of 5 mm (Lb/Sp =200). With this condition, the relative error for FOCS plasma current measurement was shown in Figure 8(a). The error is calculated from the rotation angle of output polarization state and input plasma current as explained in [4]. Another simulation was also performed to see the vibration effect on the hi-bi spun fiber which has a lower Lb/Sp ratio (~2). Using this parameter FOCS measurement accuracy simulation was performed and the result is shown in Figure 8(b).

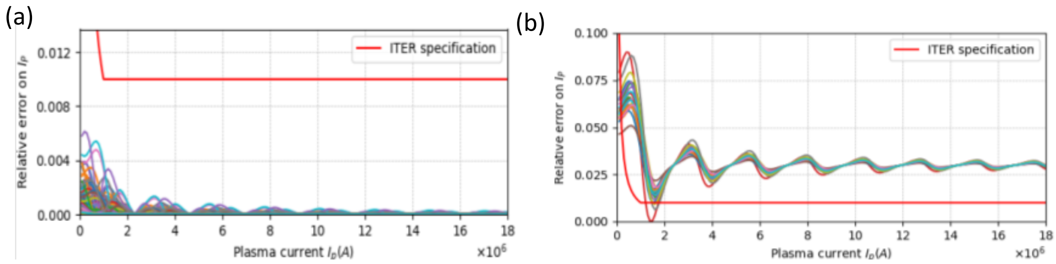


Figure 5 The simulation result of FOCS with equivalent vibration matrix on the lead fiber in bridge using (a) Lo-bi spun fiber, (b) Hi-bi spun fiber.

Compared to the results obtained for the lo-bi fiber, the relative error was much larger and did not meet the ITER requirements represented by the red curve. Lo-bi spun fibers are preferred for the measurement of plasma current in ITER.

Conclusion

In this report, we have discussed the Bridge vibration effect on the FOCS measurement accuracy. A miniature model of the bridge structure was prepared, and the vibration effect on the polarization variation was measured with the worst-case scenario. The whole structure was then modeled. Simulations were performed to estimate the FOCS measurement accuracy with influence of the bridge structure. It was found that the use of lo-bi spun fibers (Lb/Sp ~ 200) satisfies ITER specifications even in the presence of vibration, when operating in reflection with the Faraday mirror. Operation in transmission is under analysis. It is likely that in this case the measurement error exceeds the ITER limit. The effect of vibration in the hibi spun fiber was almost the same as that of the lo-bi spun fiber, but when it comes to the FOCS measurement simulation, the obtained error was larger and does not allow to fulfill the ITER specifications.

Acknowledgement

This work was partially supported by the Fonds de la Recherche Scientifique - FNRS under the convention PDR T.0252.19

References

[1] A. Gusarov, W. Leysen, M. Wuilpart, and P. Megret, "Status and future developments of R&D on fiber optic current sensor," Fusion Engineering and Design, vol. 136, 477-480, 2018.

[2] M. Aerssens, A. Gusarov, B. Brichard, V. Massaut, P. Mégret, and M. Wuilpart, in Proceeding of the 2nd Conference on Advancements in Nuclear Instrumentation Measurement Methods and their Applications, 6172868, 2011.

[3] J. Nemeth, in the ITER data base in IDM "Structural Analysis of Cryostat Bridge Cable Trays under Seismic and VDE Loads" https://user.iter.org/?uid=TVR76V

[4] F. Descamps, M. Aerssens, A. Gusarov, P. Megret, V. Massaut, and M. Wuilpart, "Simulation of vibration-induced effect on plasma current measurement using a fiber optic current sensor", Opt. Express, vol. 22(12),14666-14680, 2014