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Modelling of COMPASS tokamak PF coils magnetic fields

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Introduction

The COMPASS is a tokamak with major radius 0.56 m, minor horizontal vessel semi-axis 0.23 m and minor vertical semi-axis 0.385 m. The tokamak has maximal achievable toroidal magnetic field 2.1 T, plasma current up to ~375 kA and pulse duration up to 1 s. It is the smallest tokamak with a clear H-mode and ITER-like geometry. The COMPASS tokamak was operated between 1989 and 2001 by UKAEA (United Kingdom Atomic Energy Authority) in Culham, UK. The tokamak was offered to IPP AS CR in the year 2004 and currently is being reinstalled in Prague [1].

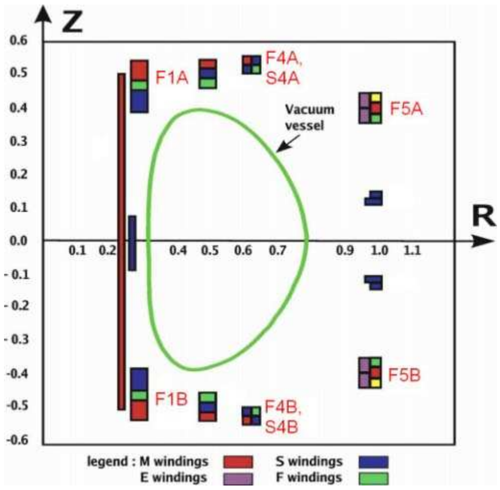

Fig. 1: The COMPASS tokamak schematics.

Poloidal field (PF) coils in the COMPASS tokamak consist of separated windings. These windings are connected into five circuits:

- MFPS - Magnetizing Field Power Supply for ohmic heating and plasma current drive
- EFPS - Equilibrium Field Power Supply for generation of the vertical magnetic field
- SFPS - Shaping Field Power Supply for shaping of the plasma cross section
- BR circuit - horizontal magnetic field for the fast feedback control of the vertical plasma position
- BV circuit - vertical magnetic field for the fast feedback control of the horizontal plasma position.

Both BR and BV circuits will be fed from in-house manufactured fast feedback power supplies (FFPS) with maximal current of 3 kA and possibility of future upgrade due to the modular design. The BR circuit will have maximal voltage range ± 100 V and the BV circuit will have ± 50 V.

Code, which integrates Biot-Savart law for toroidally symmetrical PF coil, was written and used to examine poloidal magnetic fields from the BR and BV circuits.

BV – vertical magnetic field circuit

Original BV circuit used in Culham consists of four windings: F1A, F1B, F5A and F5B (see Fig. 1). Each of these windings has two turns. Disconnecting two inner coils (F1A and F1B) from the original BV circuit will increase homogeneity and strength of the magnetic field in the major part of the plasma volume (compare Fig.2 and Fig. 3). Disadvantage of the proposed BV circuit is higher mutual inductance between BV and magnetizing MFPS circuit (see Table 1).

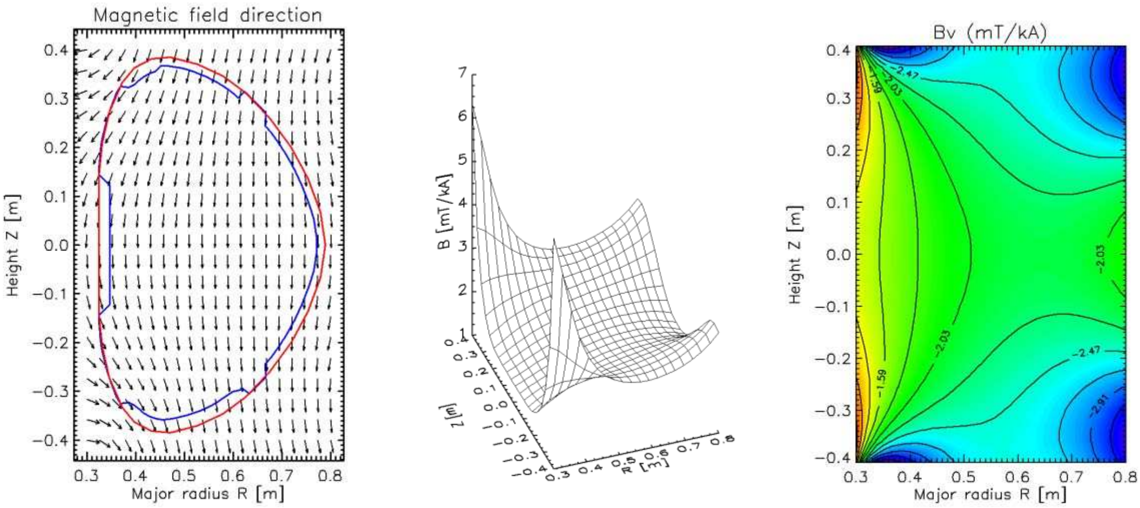

Fig. 2 a, b, c: Magnetic field of original BV circuit. Left: direction of magnetic field B, (vectors have unit length), middle: amplitude of B, right: vertical component of B.

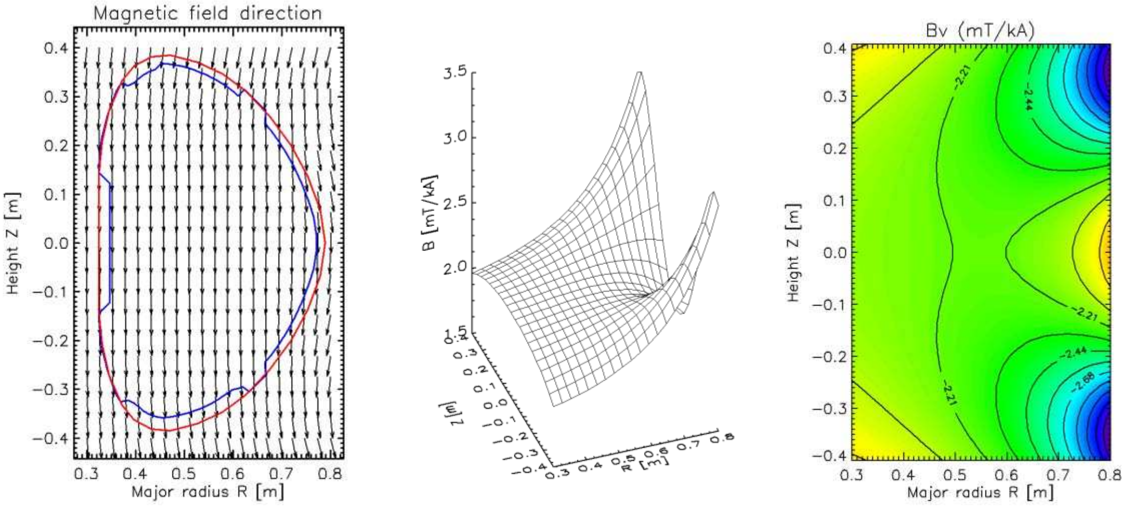

Fig. 3 a, b, c: Magnetic field of proposed BV circuit. Left: direction of magnetic field B, (vectors have unit length), middle: amplitude of B, right: vertical component of B.

BR – horizontal magnetic field circuit

Original BR circuit consists of four windings: F4A, F4B, S4A and S4B (see Fig. 1). Each of these windings has two turns. Analysis of the magnetic field, circuit inductance and skin effect of the BR circuit coils suggests that adding two inner coils F1A and F1B freed from the original BV circuit into the BR circuit and disconnecting two windings S4A and S4B from the existing BR circuit will significantly improve reaction time of the BR fast feedback circuit, bacause its self-inductance will be smaller.

Electrical circuit consisting of coil with self-inductance L and resistance R is described by equation:

$$U - L\frac{\mathrm{d}I}{\mathrm{d}t} = RI\ , \tag{1}$$

which has analytical solution $I(t) = \frac{U}{R}(1-\exp(-t/\tau))$. In a thick conductor, rapidly changing current is conducted mostly on the conductor surface because of skin effect, which is described by equation:

$$\Delta\vec{j} = \sigma\mu\frac{\partial\vec{j}}{\partial t}, \tag{2}$$

where s is conductivity and μ is permeability of material. The numerical solution of system of equations (1) and (2) shows that it is possible to reduce twice the current rise time by the suggested rearranement of the BR circuit (see Fig. 4).

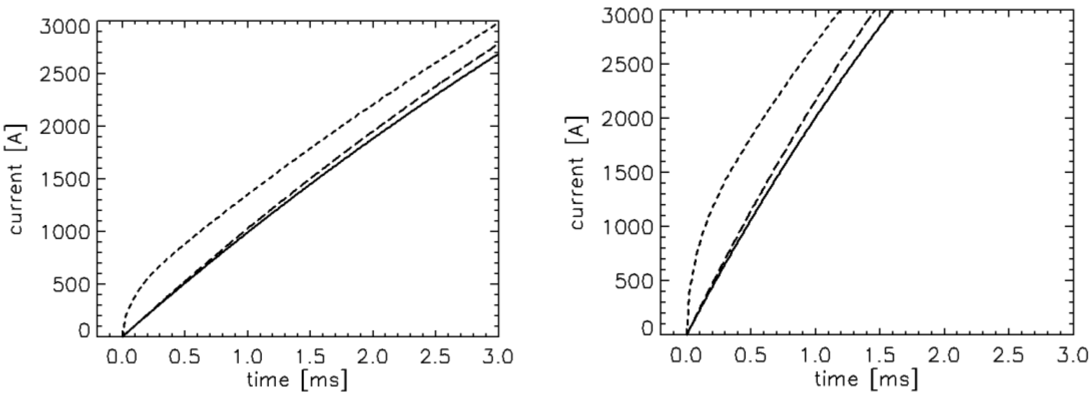

Fig. 4a, b: Left: Original BR, right: proposed BR. Continuous line: numerical solution of system of equations (1) and (2), dashed: analytical solution of equation (1) – i.e. without skin effect, dotted: surface current density multiplied by the area of the PF coil.

Vertical plasma position control requires fast change of horizontal magnetic field generated by the BR circuit. For the analytical solution of the equation (1) magnetic field change speed is not dependent on resistance of the circuit:

$$\frac{\mathrm{d}B}{\mathrm{d}t} = k\frac{\mathrm{d}I}{\mathrm{d}t} = k\frac{U}{L}, \tag{3}$$

where U is voltage of the power supply and constant k describes magnetic field from the circuit at specified location. While the current rise speed of the proposed BR circuit is doubled against the original BR circuit, magnetic field change speed is only fifty percent faster because constant *k* of the proposed BR is lower than that of original BR (see Table 1). This rearrangement yields one third decrease of the maximal attainable magnetic field, but the feedback reaction speed up and slightly more homogenous magnetic field is certainly more advantageous.

variant	coils	inductance from MFPS [μH]	self-inductance [μH]	k (0.56;0) (B_h, B_v) [mT/kA]	k (0.45;-0.3) (B_h, B_v) [mT/kA]	dB/dt (0.56,0) [mT/ms]	B_{max} [mT]
original BR	F4,S4	-0.01	92	(-2.05, 0.00)	(-2.39, -2.84)	2.1	6.2
proposed BR	F1,F4	-0.03	41	(-1.48, 0.00)	(-2.07, -1.18)	3.16	4.4
original BV	F1,F5	9	61	(0.00, -2.10)	(0.84, -2.31)	1.57	6.3
proposed BV	F5	102	56	(0.00, -2.21)	(0.17, -2.16)	1.79	6.6

Table 1: Comparison of the original and proposed PF coils circuits computed parameters. Constant *k* describes magnetic field from the circuit at specified location (R=0.56m, Z=0m or R=0.45m, Z=-0.3m).

Conclusion

The paper presents possible changes in the BV and BR fast feedback circuits in the COMPASS tokamak. The numerical modelling suggests that BV circuit might be modified to increase homogeneity of its magnetic field B. BR circuit might be modified to achieve faster reaction time.

References

1] R. Panek, et al., Czech. J. Phys. **56**, Suppl.B, B125(2006).

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