FEATURES OF TRACTION TRANSFORMER WINDINGS UTILISED AS INDUCTANCES

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Summary The paper analyses features of traction transformer design. Secondary windings of the transformer are utilized as a choke of an locomotive input filter at DC supplying system. Different ways of connection of the secondary winding coils are compared, reachable inductances are determined and forces affecting the coils are computed. The analysis is performed by FEM method for different locomotive operating modes including breakdown service.

1.INTRODUCTION

At all traction vehicles with pulse regulation of the voltage of traction motors or with voltage inverters and asynchronous motors it is necessary to insert an LC input filter. At high power vehicles an inductance of the filter represents relatively high volume and mass, is source of losses and requires cooling.

At bi- and multi-system vehicles a transformer for operation at AC systems is necessary. This transformer usually includes several windings. In principle, it is possible to use inductances of these windings for operation at DC systems. This utilization is known and used for several years (at present BR 189 [2]). This work deals with circumstances at the traction transformer for prepared design of three-system locomotive.

During function of secondary windings as inductances of the input filter the windings are passed through with current with big DC component

(hundreds or thousands Amp) and small AC component, with max. current ripple of a few Amps. To avoid supersaturating of transformer magnetic core, it is necessary to connect the windings so as to abolish its DC magnetization. In such case only leakage inductances become evident. However, the shape of magnetic field is in this case absolutely different from the shape of the transformer leakage field during operation at AC system.

For computation of the inductances it is necessary to determine shape of magnetic field excited by the currents of secondary windings. There is a three-dimensional problem, which was solved with respect to possibilities as two plane (two-dimensional) problem. These planes are perpendicular to each other and passes through axis of magnetic column, whereas first plane is in plane of sheets and another plane is perpendicular to the plane of sheets.

For solving of magnetic field software FEMM [1] was used. This software is user friendly and fast. A computation of inductance is performed from energy of magnetic field in area of the coils and current i according to formula:

$$2.W = \frac{1}{i^2} \iiint \overline{\sigma}.\overline{A}.dV = L.i^2, \qquad (1)$$

where σ is current density and A is vector potential in volume element .

The transformer for three-system locomotives consists of one primary winding, which is switchable for systems 25 kV, 50 Hz and 15 kV, 16.7 Hz, and (beside other windings) eight secondary traction windings for supply of pulse rectifiers. A basic circuit diagram, which includes switch for both transformer functions (on AC as well as DC system), is in figure 1.
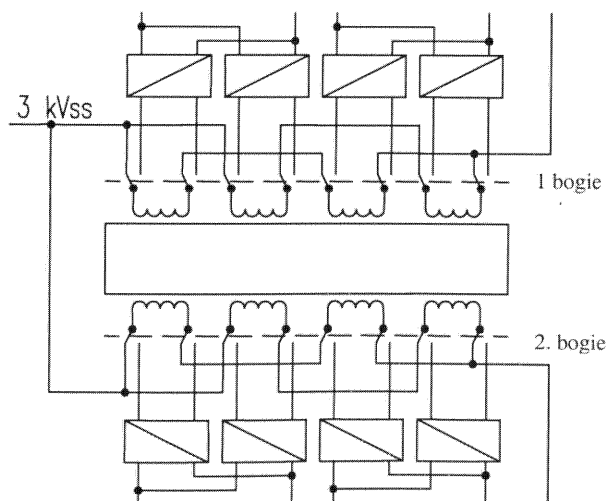

Fig. 1. A basic diagram of transformer windings for DC system.

Tapping points of the secondary windings are connected to the three-position switches, which in drawn position correspond to the operation on DC system and connect always two and two serial / parallel secondary windings as two independent inductances for electric equipment of each bogie. In reverse position the switches connect the windings to the pulse rectifiers and in central position (not drawn) the whole electric equipment of the bogie is switched off in case of its failure.
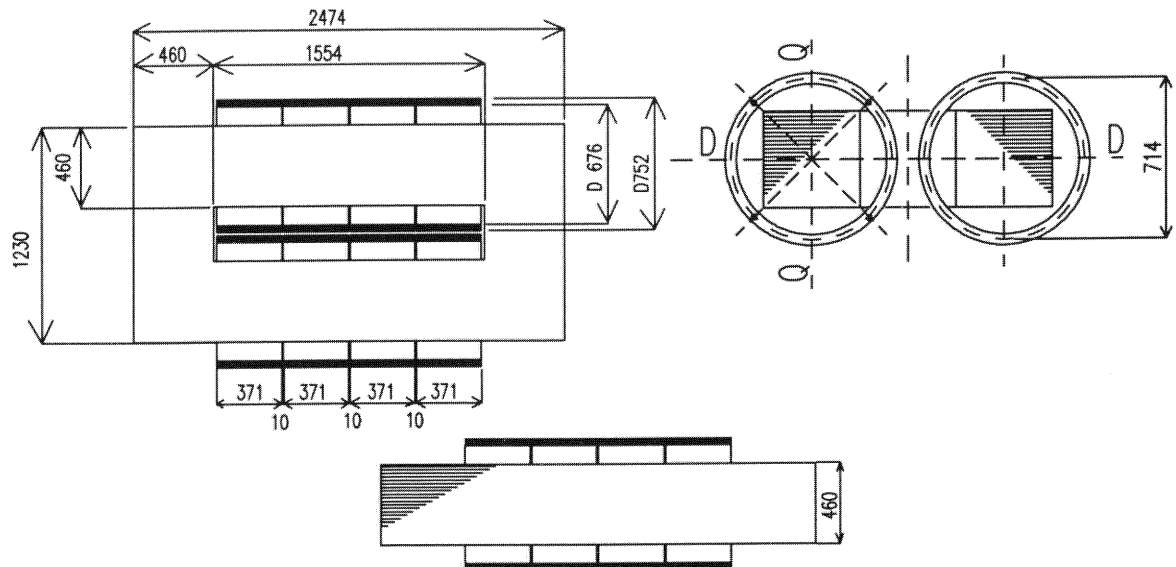

Fig. 2. Main dimensions of core and arrangement of the secondary windings .

An arrangement of the secondary windings and main dimensions of the core are in Figure 2. For wiring according to Figure 1 it is, with respect to necessity of compensation of DC components even in case of switching off the windings on one column, necessary, so that DC elements compensate on each column separately. To this requirement correspond following cases, whereas always two of them for regular vehicle operation and the last one for its breakdown service (after switching-off one system of windings).
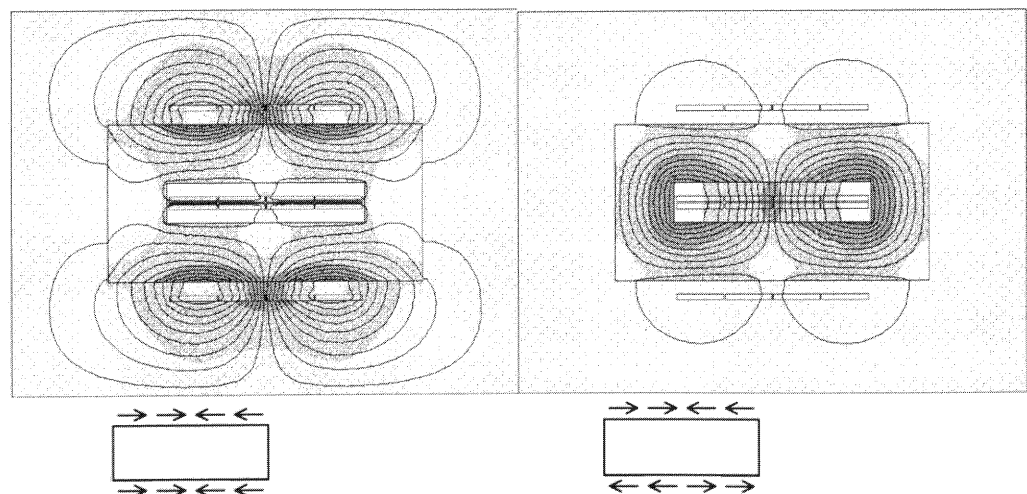

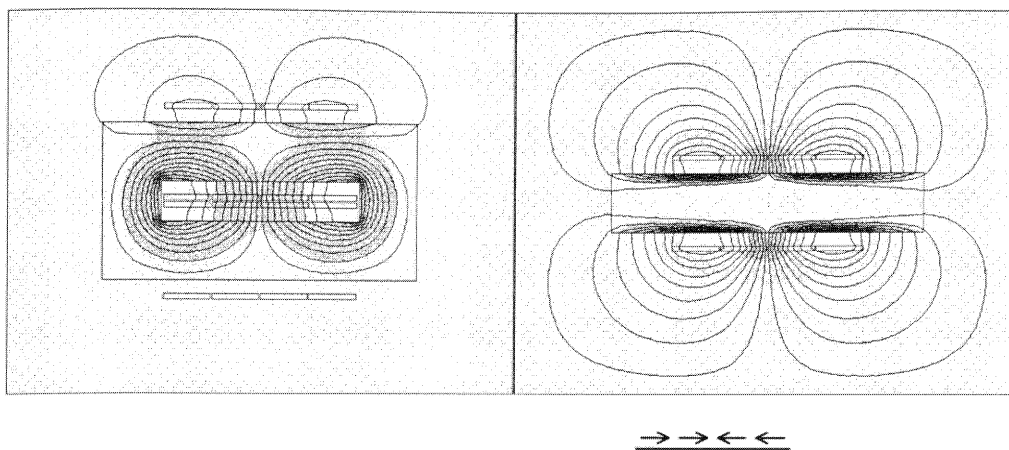*Fig. 3. Field for regular service, alternative 1, L=2,936 mH and alternative 2, L=8,280 mH.*

Fig. 4. Field for alternative 1 and 2, breakdown service, perpendicular to sheets, L=5,607 mH.

Fields for chosen cases and values of consequent inductances for one half of loco and regular and breakdown services are in Figure 3 and Figure 4.

It is also possible to use a connection, when the DC component is compensated only at complete

core. Than it is obviously necessary to change connection of windings to the switch so that the compensation was also reached at breakdown service.
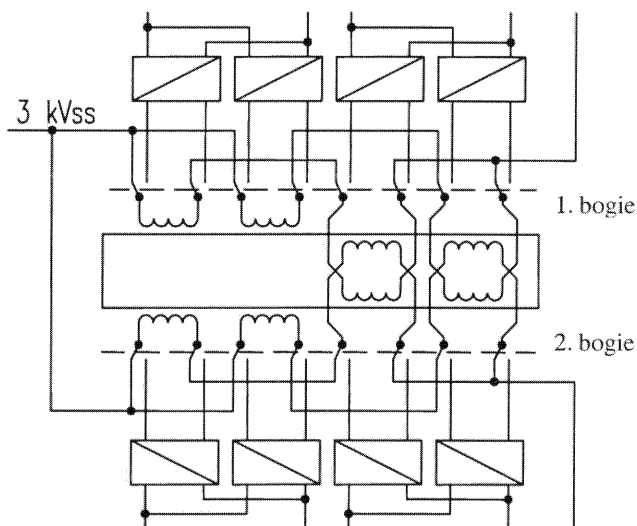

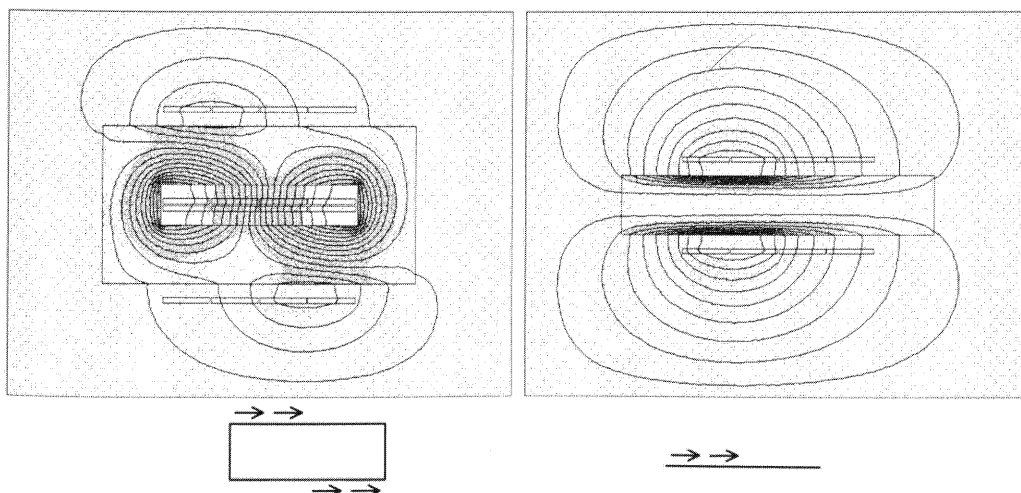*Fig. 5. An alternative of connection of windings to the switch for compensation at complete core.*

Fig. 6. Field for alternative -4, breakdown service, L=6,162 mH

For wiring of the windings according to Figure 5 conditions for regular service are identical as in case of the alternative 1, for breakdown service the fields and corresponding inductance are in Figure 6 (alternative 4).

Also wiring according to Figure 7 (alternative 3, regular service) is possible. Conditions for breakdown service correspond evidently to the alternative 4.
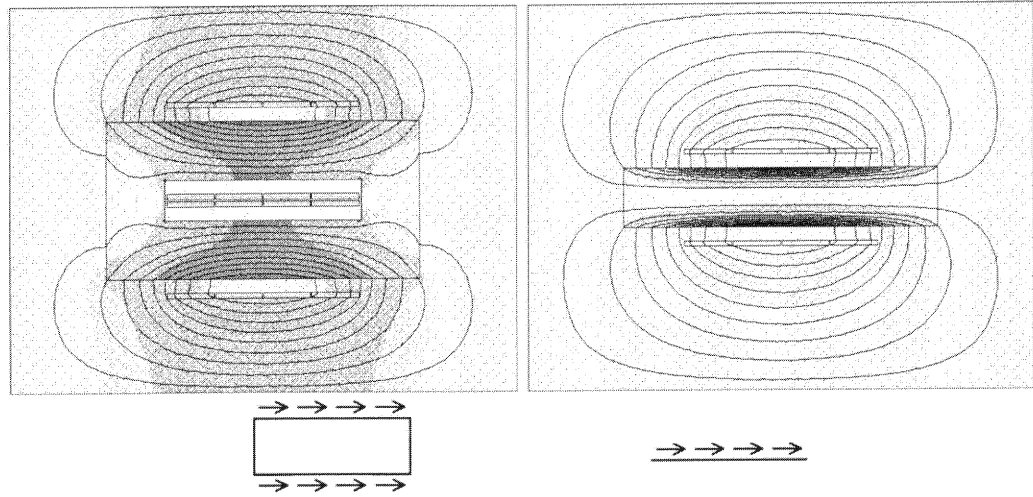

Fig. 7. Field for alternative 3, regular operation, L=7,519 mH.

2. OTHER ASPECTS

So far the alternatives were analyzed from the aspect of reached inductance. However, the way of connection of the coils has impact on other important parameters. The software [1] can also determine these parameters from computed shape of magnetic field.

For alternatives 1, 1a and 3 following forces, which represent influence of the coils in axial direction at current 1074 A, were computed:

Regular service	alternative 2	28,3 kN
	alternative 3	7,8 kN
Breakdown service	alternative 2	19,6 kN
	alternative 4	13,1 kN

For short circuit currents the forces could be evidently very high.

For service at AC system, when the secondary windings supply pulse rectifiers, mutual couplings of the secondary windings at stepped control are important. Also these couplings depend on arrangement of connection and for mentioned case their values can vary from 0,063 to 0,165.

3. CONCLUSION

It is evident that with convenient connection of the secondary windings of the traction transformer it is possible to affect importantly its final features at DC and AC systems and herewith to reduce equipment of the traction circuit. To achieve the targets, it is necessary to perform more detailed analysis of the magnetic field of the given transformer and possibilities of switching of linked circuits.

REFERENCES

[1] Meeker, D.: Finite Element Method Magnetics, Vers. 3.3, http://femm.berlios.de

[2] Kiessling, B., Thoma, Ch.: Europalokomotive BR 189, ZEVrail Glesers Annalen 126 (2002) č. 9 str. 390-399