TRACTION TRANSFORMER 1MVA, SUPERCONDUCTING, OIL-IMMERSED AND MEDIUM FREQUENCY

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Summary This paper deals with comparing 3 types of transformers - superconducting, oil-immersed and middle-frequency. These transformers can be used for locomotive as the main transformer. Weight, sizes and losses are introduced. The influence of eddy currents is describes by middle-frequency transformer. The article deals with magnetic properties of materials for higher frequency.

1. INTRODUCTION

This paper describes 3 types of transformers for locomotive. Input parameters are in Tab. 1.

Tab. 1. Parameters of transformers

Power	1MVA
No. of phases	1
Input voltage	25 kV
Output voltage	2x860V
Frequency	400, 50 Hz
Percentage impedance	30%

Superconducting transformer

Today's classical transformers with their electrical steel cores and copper windings are very efficient devices (about 99,7 %) [1]. They present a mature technology, with little room for efficiency improvement. The possibility of significant efficiency improvements in transformers with superconductor windings has long been recognized. However, the high refrigeration costs associated with very low temperature (<20 K) operation using helium have been a major barrier to the marketplace.

High temperature superconductors (HTS), with liquid nitrogen as the cryogen, directly address this barrier [2]. When compared with conventional transformers, the benefits from an HTS transformer are:

- low losses,
- reduced size and weight,
- overloadability with minimal impact on transformer lifetime,
- absence of mineral oil.

This conductor was chosen for simple availability of its characteristics. The considered current density was 50 A/mm^2.

Medium frequency transformer

Transformers have high losses at low frequencies. In 16 2/3 and 50 Hz railway systems transformer losses therefore considerably reduce overall traction efficiency. Modern power electronics allow for a more efficient and much lighter alternative: the medium frequency transformer operating at 400 – 800 Hz or comparable frequencies.

A cascade of partial IGBT inverters converts catenary current from 50 (16 2/3) Hz to 400 Hz. Each cascade module consists of two four-quadrant-controls connected by a DC link. Each module supplies one coil of the transformer operating at 400 Hz. The secondary side of the latter consists of only one coil directly connected to the rectifier and the usual motor inverters. The load-side rectifier has to be adapted to 400 Hz. This is the only modification required.

The medium frequency transformer is inherently multi-system operable. In order to use different AC or DC supply, it suffices to modify the software controlling the catenary-side inverters.

Motivation

Weight and volume

The under-floor space for integrating the main transformer into an SR (suburban railway) is very limited. Small and light transformer technology is therefore an important requirement for decentralized traction.

Multi-system operability

The medium frequency transformer is inherently multi-system operable.

Energy efficiency

Efficiency of medium frequency transformers: > 94% (Efficiency of conventional transformers: ~ 85-90%)

Transformer efficiency (and with it the overall efficiency of power train) increased by 3 – 5%. It is assumed that the same efficiency gain can be obtained for higher power classes as well, e.g. high-speed trains or freight locomotives.

Oil-immersed transformer

For locomotive transformer, because of its output, low mass and low losses are required. The transformer must be resistant to frequent short-circuits and atmospheric over-voltage and that is why they have rather high u_K. It must stand considerable mechanic loading, the construction parts must resist vibrations, it should stand 3g overload and should not be damaged in a locomotive crash. Magnetic circuit does not differ from common transformers. In winding the current density is about 7 A/mm^2, which is twice as much in comparison with energetic transformers and better conductor insulation must be used. Oil cooling is usually used with forced circulation.

2. DESIGN AND PARAMETERS [2]

2.1. SUPERCONDUCTING TRANSFORMER

was modeled 1MVA transformer, fig.1. [1].

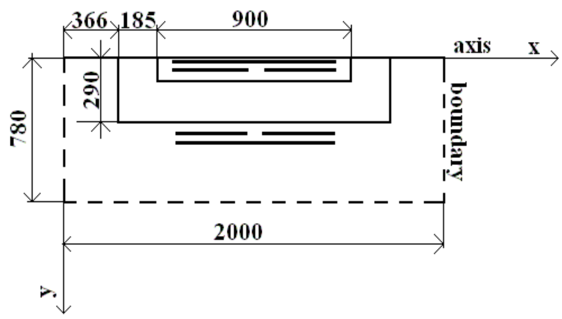

Fig. 1. Sectional view of the transformer / one half /

Weight of magnetic parts

Weight of windings HV
m_{HV} = 71 kg

Weight of windings LV:
m_{LV} = 90 kg

Weight of magnetic circuit
m_{mc} = 509 kg

Losses in winding of transformer
with penalty factor 10

Total losses 15.62 kW

2.2. OIL-IMMERSED TRANSFORMER

Weight of windings HV
m_{HV} = 236 kg

Weight of windings LV:
m_{LV} = 166 kg

Weight of magnetic circuit
m_{mc} = 617 kg

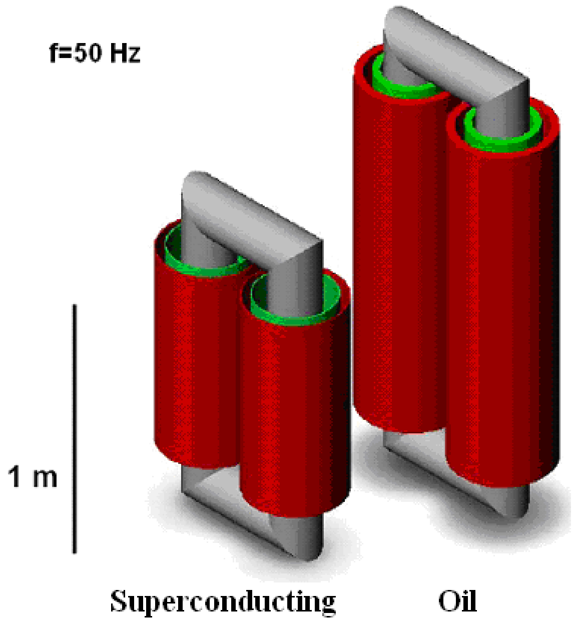

Fig. 2. Comparison – oil-immersed versus superconducting transformer

Basic losses /R*I^2/ [kW]	54
Eddy current losses [kW]	2
Field's coeficient	1,04
Total losses [kW]	56

Fig. 2. shows two types of transformer – comparison of sizes.[2].

2.3. MEDIUM FREQUENCY TRANSFORMER

Weight of windings HV
m_{HV} = 101 kg

Weight of windings LV:
m_{LV} = 59 kg

Weight of magnetic circuit
m_{mc} = 197 kg

Total losses of the transformer for 400Hz was calculated with using software MAGFORT2D [3]. The program MAGFORT2D is determinated for calculation of the electromagnetic field in the transformers /specially/.

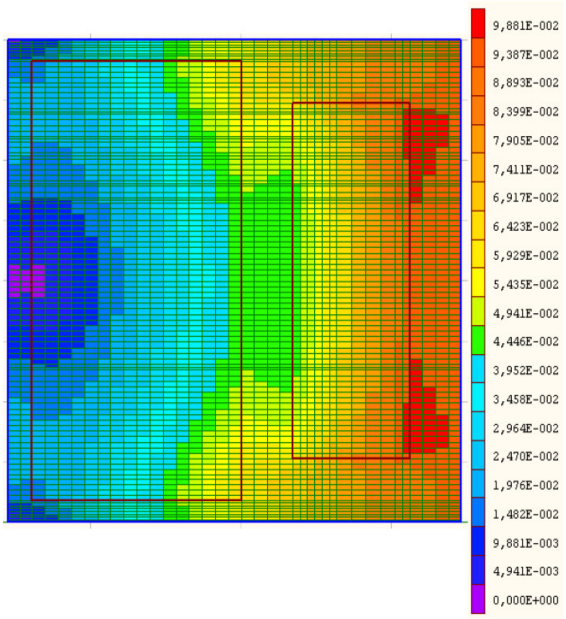

Fig. 3. Map of magnetic field

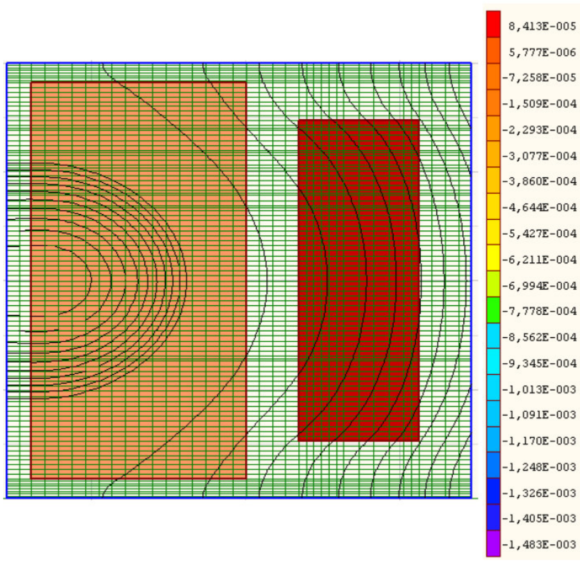

Fig. 4. Distribution of vector-potential A

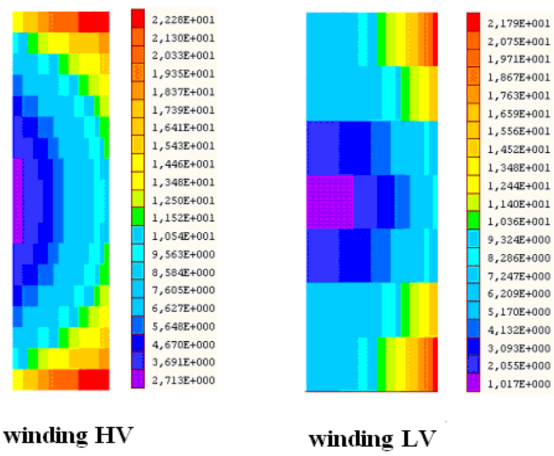

Fig. 5. Distribution of losses in winding

Tab. 2. Parameters of transformers

Basic losses [kW]	1,55
Eddy current losses - Bx [kW]	1,53
Eddy current losses - By [kW]	1,97
Eddy current losses - total [kW]	3,50
Field´s coeficient	3,11
Total losses [kW]	5,05

3. COMPARISON OF TRANSFORMERS

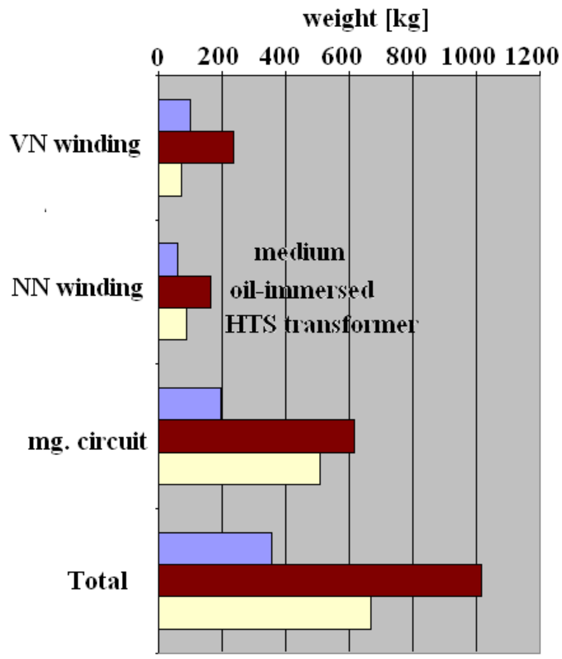

Fig. 6. Comparison of transformers

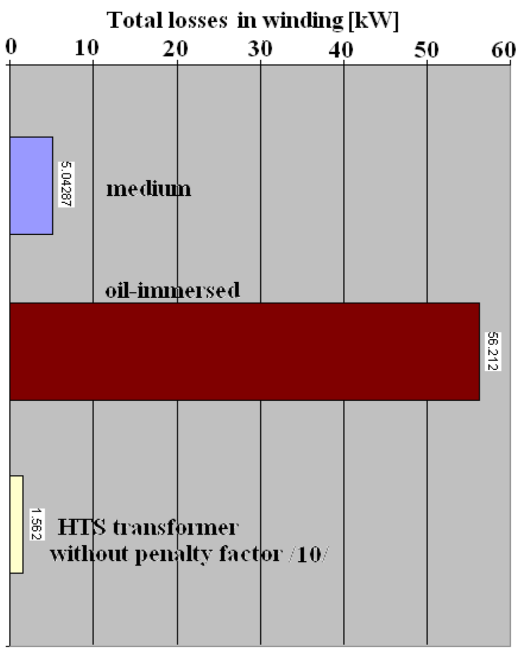

Fig. 7. Total losses in winding

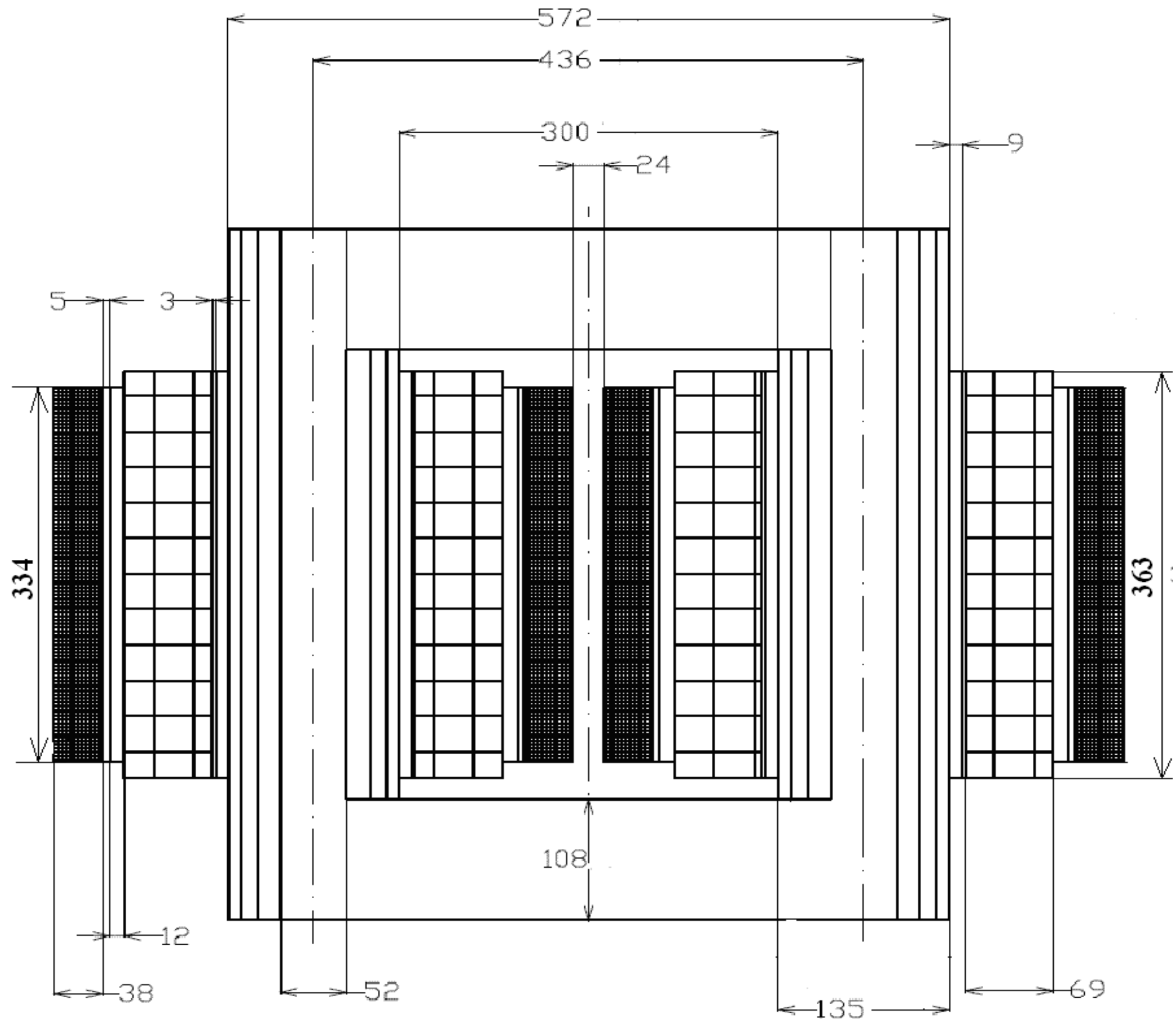

Fig. 8. Geometrical sizes of medium transformer

4. CONCLUSION

Result of this paper is comparison of 3 types traction transformers. The price of the transformer is not introduced – it is very difficult. The power of transformers was chosen 1 MVA. We can submit:

- HTS transformer is very interesting – losses and sizes. The price of the HTS wires is about 60-70 USD/m.
- Oil-immersed transformer has maximal losses and weight.
- Medium transformer is very prospective. The ratio of POWER/SIZES is very interesting. The crux of the design of the transformer is determination of the eddy current losses – optimization of windings.

Acknowledgement

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