Shaft vibration suppression by manipulating the poles

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Introduction

Strong shaft vibration has been recorded at the 40 MW bulb unit A of the Dubrava HPP on the Drava river in Croatia. In order to identify and eliminate the cause, air-gap and magnetic flux distribution data were examined in detail (Fig. 1) [1]. The understanding of the rotor kinematics and dynamics thus obtained enabled modifications of critical mechanical details, which in turn resulted in substantially lower shaft vibration levels (1, 2 and 3 in Fig. 2) [2]. An alternative solution for suppressing vibration was proposed and preliminarily checked [2]. It consists of bringing the rotor magnetic forces into balance by bypassing the windings of one or two suitably selected poles. Here, a report is given on the full-scale experiment in which this approach was verified.

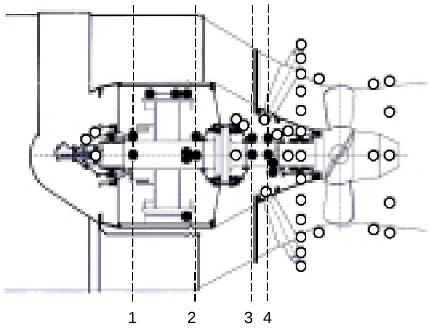

Fig. 1 - Unit A of the HPP Dubrava with sensors used in multidimensional diagnostic tests [1]. The sensors denoted by solid symbols (air gap, magnetic flux, relative shaft vibration, revolution speed, synchronisation pulses) were used in the experiment described here.

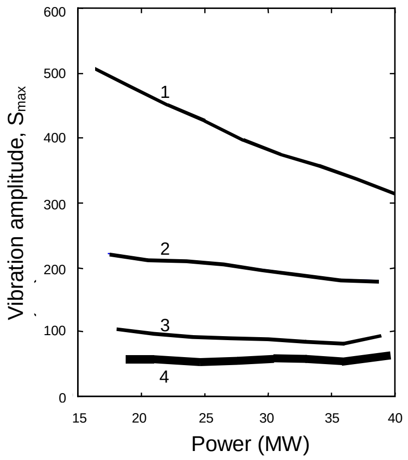

Fig. 2 - Unit's vibration history [2]: 1 - initial state, 2 - rotor centred, 3 - rotor counter-centred; 4 - result of the experiment described here

Rationale

A typical form of the circumferential dependence of the air gap and the magnetic flux density found at speed-no-load in unit A is shown in Fig. 3. The rotor is slightly eccentric. This results in a deviation of the magnetic flux curve from the zero-centred circle, which produces a non-zero vector sum of the flux densities of the poles. In the present case, this value, RM, equals a typical contribution of a single pole. Thus, the first idea on how to compensate for the eccentricity by means of manipulating the poles might be to bypass the pole located in the direction of the resultant. However, as shown below, this would not be correct.

If the spider is in perfect alignment, there is no kinetic deflection of the shaft when the generator is excited, and the distribution of the magnetic flux is uniform. However, if there is a spider-to-shaft misalignment, switching on the excitation results in an increase of the magnetic flux density at the poles located within the angular segment with the smaller air-gap. This makes the attraction force in this region stronger, and the final result is a radial shift of the shaft.

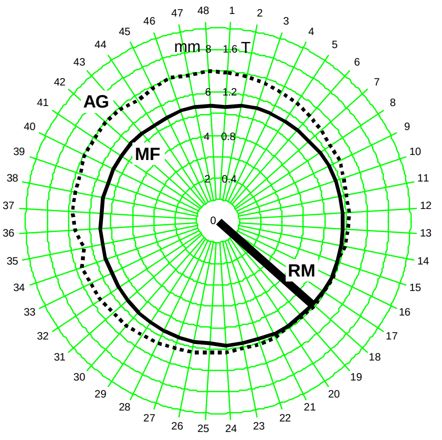

Fig. 3 - Distribution of air gap, AG (mm), and magnetic flux density, MF (T), over the 48 poles in the generator recorded at speed-no-load; RM stands for the resultant of the magnetic flux density.

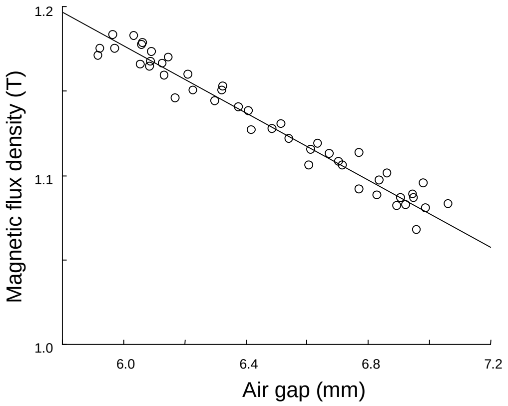

Fig. 4 - By sorting the MF-AG values found at the poles (Fig. 3), a generator magnetic characteristic is obtained.

Now, if, by manipulating the poles, the vector sum of the flux densities of the poles is reduced to zero, there will be no kinetic deflection when the excitation is switched on and the generator is loaded.

Therefore, it is not the full final vector sum, the one at speed-no-load or under load, that has to be eliminated, but only its component that would exist prior to kinetic deflection. How to estimate the magnetic flux density component that would be produced by the eccentricity in mechanical touring? By means of the magnetic characteristic, presented in Fig. 4, which can be used to map the corresponding air gap data into an estimate of the virtual magnetic flux density data.

In the case considered here, different eccentricities have been found at different axial locations in the generator. The mean eccentricity, approximated by the vector sum of the eccentricities at the two opposite sides of the generator, was used as an input data for the mapping procedure described.

Choice of poles

The mean values of the magnitude and the direction of the resulting *no-deflection* eccentricity, as found in several tests, correspond to 0.212 T at the angular position 23.1 in the scale of poles. The value of the magnetic flux density of a typical pole at speed-no-load is approximately 1.15 T. Therefore, it is necessary to eliminate 0.212/1.15, i.e. 18.4 % of the action of pole 23. If no partial bypassing of the windings is made, two poles have to be bypassed in order to make the sum of their fluxes approximately equal to the resultant.

If two poles one-pole distant from the opposite-lying pair are bypassed, the vector sum of their flux densities would amount to approximately $2\pi/48$ of the mean value, 48 being the number of poles. A two-pole distance from the opposite pair would result in the relative amount $4\pi/48$. Thus, either 13 % and 26 % of the mean pole flux density value can be achieved by such configurations, while 18.4 % is needed. Therefore, the suitable configurations of the bypassed poles that are at least approximately centred at pole 23 would be: 11 and 34 or 12 and 35 for the one-pole step, and 12 and 34 for the two-pole step.

Due to the construction details of the Dubrava generators, it would be rather difficult to install the bypasses on even-numbered poles. Thus, the one-pole step combinations cannot be set, and the same holds true for the noted two-pole combination. The compromise combinations closest to the optimum are thus: 13 and 35 or 11 and 33. The first of these two combinations has been chosen, and an additional related configuration has also been checked. Thus, the full programme of the experiment comprised the following:

A Poles 13 and 35 bypassed ... as the optimum configuration,
B Poles 13 and 33 bypassed ... as a sensitivity check of the optimum configuration,
C No bypassed poles ... as a reference.

The magnetic field found for the configuration C (at speed-no-load) is illustrated in Fig.3, and that for A (under load, at 33 MW) in Fig. 5.

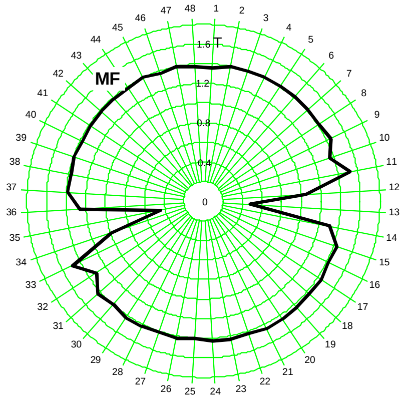

Fig. 5 - Intervention in the magnetic field made in the configuration A

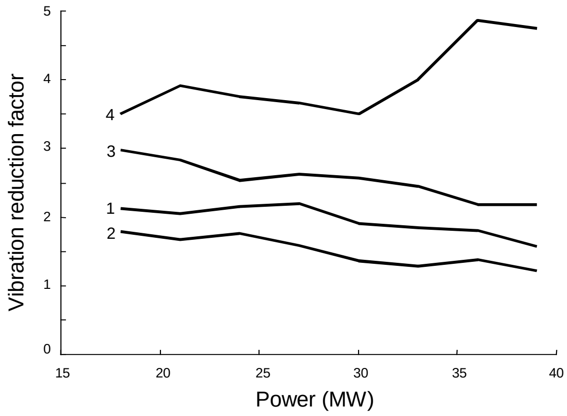

Fig. 6 - Normalised results of the experiment: the ratio of the vibration amplitude with all poles functioning and with poles 13 and 35 bypassed (configuration C/configuration A). The four curves refer to the four planes denoted in Fig. 1.

Results

The suppression of the shaft vibration achieved by means of the optimal configuration, A, is illustrated in Fig. 6. As can be seen, lowering the shaft vibration amplitude by a factor between 1.5 and 4 or more has been achieved. However, the measured effectiveness of the method strongly depends on the location along the shaft. The result presented as 4 in Fig. 2, refers to the optimum configuration, A, in the worst location, 2.

Another way to assess the result is to check rotor sensitivity to the magnetic loading, Fig. 7. A tiny kinetic deflection in the optimal configuration, A, compared to the normal one, C, shows that the rotor became quite stable.

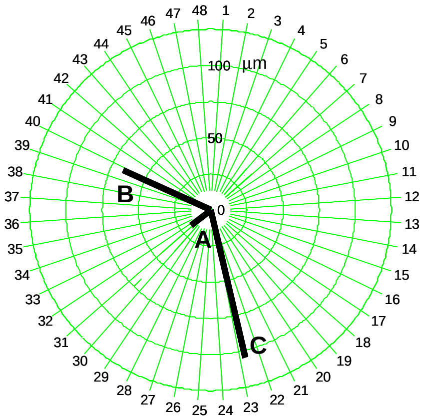

Fig. 7 - The magnitude and the direction of the change of the rotor eccentricity (kinetic deflection) due to switching on the excitation, as found for the three configurations tested

Discussion

The non-zero residual response to the magnetic loading (A in Fig. 7) is the consequence of the fact that configuration A is the only practical approximation of the true optimum. As shown by the sequence of vectors A-B-C, the optimum is rather sensitive, and a fine adjustment, which would be possible if a pole or poles could be partly eliminated by bypassing only a part of winding, would result in an almost zero magnetic vector sum and a virtual elimination of the source of vibration considered.

Two effects might limit practical applicability of the method: the electric and thermodynamic consequences of the circumferentially uneven magnetic excitation caused by the bypasses. Only the first effect has been checked to date; a negligible increase of voltage and current distortion induced by the bypasses has been recorded [3].

Conclusions

Shaft vibration in a hydro-power unit caused by the spider-to-shaft misalignment can be effectively suppressed by manipulating the magnetic field through bypassing a part of one pole or a pair of poles.

The method of selecting the poles that need to be bypassed has been devised and verified.

The deterioration effects of bypassing the poles have not yet been studied satisfactorily.

Acknowledgement

Mr. Josip Sabolek of HPP Dubrava took part in an earlier pilot test. His help in the realisation of this experiment was crucial and is acknowledged.

References

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