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Online efficiency diagnostic of three phase asynchronous machines from start up data

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Abstract. In this paper a real time efficiency determination of three phase asynchronous machines is described. Such an online tool improves the reliability of the machines and its maintenance costs. There are various methods to determine the efficiency of three phase induction machines. But all of them have in common that they are to inaccurate or they are impracticable.

Here, the machine efficiency will be derived from start up data. For that purpose the variation with time of all stator currents and all stator voltages have to been measured. No additional data and no additional measuring devices, such rotor speed or torque measurement shaft are needed.

Key words

Three phase induction machine, online efficiency monitoring, start up data, maintenance costs.

1. Introduction

Nowadays a cost effective operation of three phase induction machines is absolutely necessary to save energy and maintenance costs. For this reason a simply method to determine the machine efficiency is needed. From fifteen motor efficiency methods only two of them are useable because of the error limits. The air-gap torque method and the shaft torque method have an anticipated error limit within 0.5%. The first one needs the no-load point and the torque must be measured by the second method. Both conditions are very rarely, because the motor shaft is normally connected and torque measurement shafts are too expensive.

2. Method

The described method bases on the current circle diagram of an induction machine. At the beginning it must be pointed out that the presented method can use for each type of three phase induction machines such as slip-ring and squirrel cage induction machines. The shaft torque and subsequently the motor efficiency can be derived from Ossana's circle. In order to get the diagram two points are needed at minimum. The stand still point at rotor speed zero and the no-load point at nearly synchronous speed of the machine. Both points are measured during the start up of the machine, but both points must be corrected due to differences between the real and theoretical conditions of operation. For the stand still point it means that a few of line periods are used to determine the current amplitude. Fig. 1 shows the stator currents of the phases during an unloaded start up. The different amplitudes of the currents cause by the damped direct currents of each phase. The amplitudes of these currents depend on start up time.

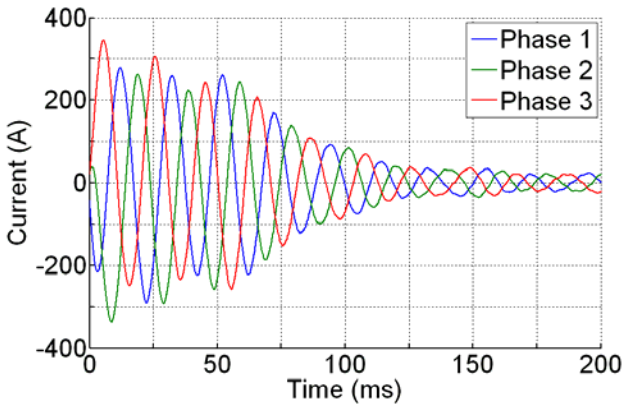

Fig. 1. Time variation of the stator currents during an unloaded start up.

An useable number of current amplitudes causes by a large moment of inertia of large machines or nearly full load machine. These requirements are always met in practice. To get acceptable results from the current circle diagram of squirrel cage motors it must be presented by two circles because of the saturable leakage inductances and frequency-dependence rotor resistance. The stand still point presents the so-called start up circle. The circle is constructed by the mean of the diameter.

$$d = \left(U_1 - I_m \cdot X_{1\sigma}\right) / X_k \tag{1}$$

Equation (1) shows that the diameter depends on the stator voltage, the magnetizing current of the machine and the leakage reactances of the stator and the rotor. The leakage reactances can be derived by the stand still point because the phase angle between the stator voltage and the stator current is known. The second circle will be presented by the no-load point respectively a point between no-load and nominal load.

3. ANALYSIS OF MEASUREMENTS

A. Space Vector

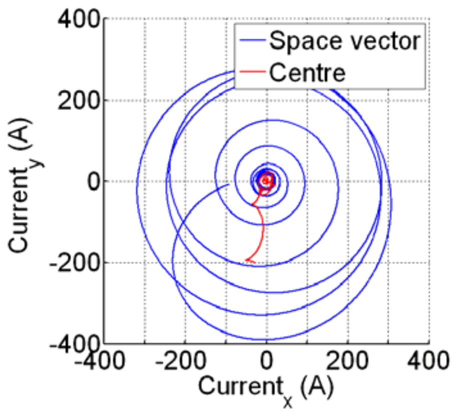

Fig. 2. Space vector of the unloaded start up.

To estimate the stand still current for all load cases, it is necessary to adjust the phase currents by the transient currents. This can be realized with the space vector of the currents. Normally the centre of rotating current is in origin of the coordinate system. But the transient currents shift the centre out of the origin. It is difficult to find the exact centre of the space vector. Consequently the current amplitudes are inaccurate. But if the zero crossings of the current curves are used, the error can be minimized to useful limits. The phase angle between the supply voltage and the stand still current can be estimated by the difference of the amplitudes between the voltage and the current.

4. CURRENT CIRCLE DIAGRAM

B. Construction

The current circle diagram can be constructed by various options. First, it can be derived from the equivalent circuit of an induction machine. In the case of an induction machine with a squirrel cage the current circle diagram consists of uncountable circles which depend on the shape of the rotor slots. And without knowing about the shape of the rotor slots these circles, especially the diameters can neither calculated nor estimated from other machine characteristics.

But from experiments can be learned that the motor efficiency can be derived from two circles. The red circle is constructed by the short circuit point and the no-load point. The small red circles present the measured values. And the blue circle bases on the working point and the no-load point. Fig. 3 shows that the test points correlate up to the nominal point very good with the blue circle. Only when the machine is overloaded the red circle is needed. The results obtained by such simplified method have error limit within 0.5%.

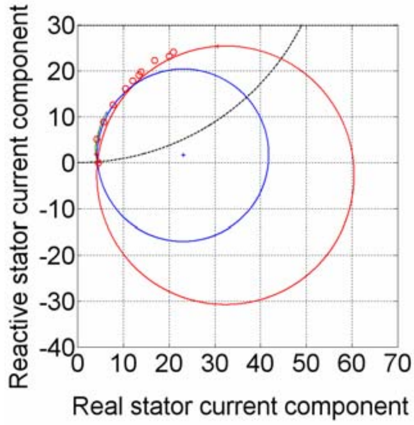

Fig. 3. Current circle diagram of a squirrel cage induction machine.

C. Motor shaft torque

The motor shaft torque can be derived from the current circle diagram, too. But therefore an additional line between the no-load point and the so-called infinite point must be constructed. The infinite point can be found by an additional circle. This circle is given in Fig. 3 by the dotted black line.

Because of the missing speed information the speed-torque characteristic isn't meaningful. For this reason Fig.4 shows the current-torque characteristic.

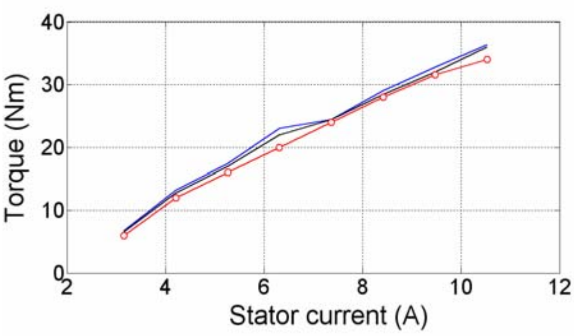

Fig. 4. Stator current-torque characteristic (static) of an induction machine.

5. Conclusion

The method to determine the motor efficiency of induction machines described in this paper bases on current circle diagram. The error limit is smaller than 1% when the working point is between 50 and 100 per cent of the nominal power. If it is nearly the un-load point the error will be increase. It must be pointed out that the presented method fulfils the error limit for each type of three phase induction machines such as slip-ring and squirrel cage induction machines.