Induction Machine Faults Leading to Occupational Accidents

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Abstract. In order to obtain high performance and safety degree in machine operation it is necessary to identify potential machine faults. Such faults may have an effect on the machine itself but may also lead to accidents at work. Thus, the activities aiming at the identification of the relation between the failure causes and their effects seem to be necessary to be undertaken. With this purpose, the first part of the paper concerns the analysis of machine faults. In order to achieve it, induction machines are chosen and are widely discussed. In the next part of it the issues of occupational risk are presented, in particularly statistical data about accidents at work in Polish enterprises. It allows to determine the problem of faults and their influence on workers' safety in industrial environment.

Keywords: induction machine, occupational accident, machine fault.

1 Introduction

Recently, design methods are perceived as well-developed fields which cover consumer products, machinery, software, architecture and arts. Not only do they allow to find simple solutions to existing problems but also to interrelated with one another (Anggreeni & Voort, 2013). In order to perform a set of functions, which solves these problems, various product robust design methods are applied (Phadke, 1989; Mrugalska & Kawecka-Endler, 2012; Mrugalska, 2013a). Furthermore, numerous approaches for fault detection of the product or its components have been built up (Ding, 2008; Isermann, 2005; Mrugalski & Witczak, 2012; Mrugalski, 2014). These methods are very crucial and vital in the case of complex products as they allow early fault detection of their components which may help to limit the range of the fault and resulting economic losses (Hughes et al., 2012, Mrugalska & Arezes, 2013). However, regardless of increasing know-how it is still compulsory to remember about assuring safety of machinery and people operating them (Gambatese, 2000; Ridley & Pearce, 2006; Butlewski, 2012; Górny, 2012; Górny & Mrugalska, 2013; Mrugalska & Arezes, 2013).

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As every day, 6,300 people die due to occupational accidents or work-related diseases, what constitutes more than 2.3 million deaths per year, this problem has become one of the most important ones in contemporary world. It is particularly visible in developing countries, where a huge part of the population is at risk resulting from being engaged in hazardous activities, such as agriculture, fishing and mining (Safety at work, 2013). It is worth to emphasize that even in some countries where the development of technology, application of protection on work stands, control of the course and realization of processes and implementation of preventive actions are on high level, the number of accidents is also high. In most cases it results from the fact that the process of risk identification and assessment and implementation of risk control strategies is obeyed or not done properly. Moreover, there is sometimes even lack of awareness of existence of potential accident risk from both points of view: workers and also employers. Such state requires taking radical and efficient actions leading to upgrading working conditions and to raising the awareness and culture within the range of not following security (Hankiewicz, 2012; Kawecka-Endler, 2003; Kawecka-Endler & Mrugalska, 2011; Tytyk, 2008).

In this paper a particular attention is paid to occupational accidents which are caused by machine faults in industrial environment. The presented data concern Polish enterprises in years 2008-2012.

1.1 Machine Faults and Their Causes

Machine faults are a major area of concern for the contemporary manufacturing industry as they result in production downtime. Data show that half of the cost related to manufacturing operations is connected with maintenance (Hughes et al., 2012). Thus, an increasing demand has appeared to diagnose systems as it can help to reduce machine downtime by determining the root causes of faults after they happen. It is advisable to do on-line monitoring of the machine variables by taking measurements to diagnose the state of the machine when it enters into the fault mode (Ding, 2008; Isermann, 2005; Mrugalski & Witczak 2012; Mrugalski, 2013). It is shown that "the sooner the cause can be determined the sooner a corrective measure can be implemented and the machine put back online" (Hughes et al., 2012).

Machine fault (or a machine failure) can be defined as "any change in a machinery part or component which makes it unable to perform its function satisfactorily or it can be defined as the termination of availability of an item to perform its intended function" (Jayaswal et al., 2008). However, before the final fault takes place it is possible to notice incipient fault, distress, deterioration, and damage (Bloch & Geitner, 2005), what makes their part or component unreliable or unsafe for continued use (Mrugalska & Kawecka-Endler, 2011). In practice there are many reasons why machine faults can occur, for instance design faults, improper assembly, material defects and exceeding the initial design conditions during operation (Hughes et al., 2012). Their range may be minor or catastrophic. However, two types of the most often appearing faults can be differentiated: internal and external, as presented in Table 1.

Table 1. Categorization of induction machine faults (Adapted from (Singh & Kazzaz, 2003; Casimir et al., 2005)

Type	Subtype	Examples
Internal	Electrical	bar breaks, dielectric failure, insulation fault, magnetic circuit failure
	Mechanical	bearing faults, coil and sheet steel motion, contact between stator and rotor, rotor strikes, static or dynamic eccentricity
External	Electrical	noisy network, voltage fluctuations, unbalanced voltage
	Environmental	cleanliness, humidity, temperature
	Mechanical	assembly fault, pulsating load, overload

Table 2. Exemplary causes of induction machine faults (Adapted from (Kazzaz & Singh, 2003; Stack et al., 2005; Trigeassou, 2011))

Machine element fault	Subcategory of machine element fault	Causes of machine element fault
Bearings	Ball bearing	excessive load, increased noise level and vibrations, leakage current induced by multilevel inverters, lubricant contamination, variations in the torque load
Rotor	Conductor displacement	frequent starting, shock, winding vibration
	Connector failure	conductor pressure, excessive vibration
	Fault between coils and the stator frame	angular points in the slots, bad insulation, coil pressured by the frame, shock, thermal cycle
	Frame vibration	bad installation, coil vibration, contact with the rotor, magnetic imbalance, overload, power supply imbalance
	Insulation fault	extreme temperature condition, frequent starting, insulation damage during installation
	Inter-phase short-circuit	high temperature, imbalanced supply, insulation failure, slacking of coils
	Inter turn short-circuit	excessive temperature, high humidity, overvoltage, vibration
Stator	Bar breaks	high temperature, lack of cleanliness, loss of lubricant, magnetic imbalance, overload, thermal fatigue, unbalanced load
	Bearing fault	bad installation, high temperature, lack of cleanliness, loss of lubricant, magnetic imbalance, overload, unbalanced load
	Bearing lubricated badly	bad quality of lubricant, excessive temperature
	Magnetic circuit failure	manufacturing fault, overload, thermal fatigue
	Mechanical imbalance	alignment problem, short-circuit ring movement
	Misalignment	bad installation, bearing failure, magnetic imbalance, overload

As it can be seen external faults concern environmental disturbances which can result from natural causes or derive from the activities of humans (Mrugalska, 2013b). Moreover, both internal and external faults refer to components of electrical and/or mechanical part of the motor. It is worth to emphasize that it is investigated that more than 40% of induction machine failures concern mechanical subtype (Trigeassou, 2011). They are mainly bearing, rotor and stator failures (Akin & Rahimian, 2013; Choi, 2013; Thorsen & Dalva, 1995; Bonnett & Yung, 2008). The exemplary of them and their causes are shown in Table 2.

2 Materials and Method

The purpose of this study was to analyse and determine the most popular induction machine faults and their causes. This knowledge is very crucial and vital as it may provide data about possible working conditions of operators. For this aim, three primary activities were undertaken: a review of the literature, an investigation of failures for a chosen group of machinery such as induction machines and analysis of data about working conditions in the European Union countries, particularly in Poland. On the basis of statistical data, the problem of faults, which may have the major effect on workers' health and safety, was emphasized.

3 Results and Discussion

In Poland frequency rates of job-related fatalities and occupational diseases are much higher than registered in the 15 former traditional EU states (Eurostat, 2012). For example, in 2011, the overall number of individual and mass accidents at work amounted to 96573 that account 0.4% of the total number of accidents. On the other hand, the number of people injured in mass accidents at work amounted to 1,078 persons what comprise 1.1% of the total number of the injured. It should be emphasized that after a significant decrease in the total number of persons injured in 2009, in 2010 an increase (8.2% compared to the previous year) in the number of injured persons in accidents at work was notified, and then in 2011 a further increase (3.2%) was identified (Central Statistical Office, 2012). The causes of occupational accidents in Polish national economy in years 2008 - 2012 are shown in Figure 1.

As it can be noticed more than half of causes of accidents, in the successive years after 2007, comprised a group of incorrect employee action. This group encompass inadequate concentration on a performed activity, a surprise with an unexpected event, lack of knowledge about hazards and regulations concerning occupational health and safety and inappropriate pace of work and lack of experience. Another cause of accident was inappropriate general organization (ca. 11%). In this group it was taken into account inappropriate organization of work in which dominated: inappropriate co-ordination of collective work, tolerance of violation of occupational health and safety regulations by supervisors, work performed by too small number of

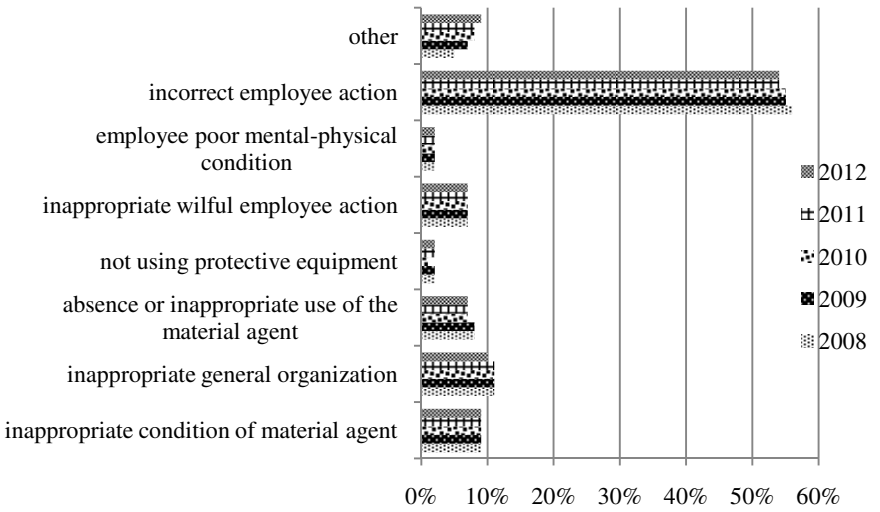

Fig. 1. Causes of actions leading to injury (Source: adapted from (Central Statistical Office, 2009; 2010; 2011; 2012; 2013))

people and inappropriate organization of a working place which most often caused accidents due to inappropriate passages and routes leading towards a working place or storing and not removing dispensable objects and substances around a working place as well as lack of a personal protection. A less numerous group, however, the most important for the aim of this paper, was inappropriate condition of material agent (ca. 9%). In these statistics material agent includes:

- "material agent connected to the specific physical activities performed by the victim at the moment of accident is a machine, tool or other object used by the victim at the moment when the accident occurred;
- material agent connected with the deviation in a machine, tool, other object or environmental factor that is directly connected to the deviant event;
- material agent that is a source of injury comprise machine, tool, other object or environment factor the contact with which caused injury (physical of psychical)" (Central Statistical Office, 2012).

Analysing in details material agent four groups of causes can be identified as follows:

1. constructional defects or inappropriate technical and ergonomic solutions of a material agent,
2. faults of material agent,
3. inadequate quality of the material agent manufacturing mainly failing to comply with required technical parameters or appliance of substitute materials,
4. inappropriate exploitation of a material agent, i.e. overexploitation, insufficient conservation and inappropriate maintenance and repairs.

The data concerning them from 2012 are presented in Figure 2, respectively.

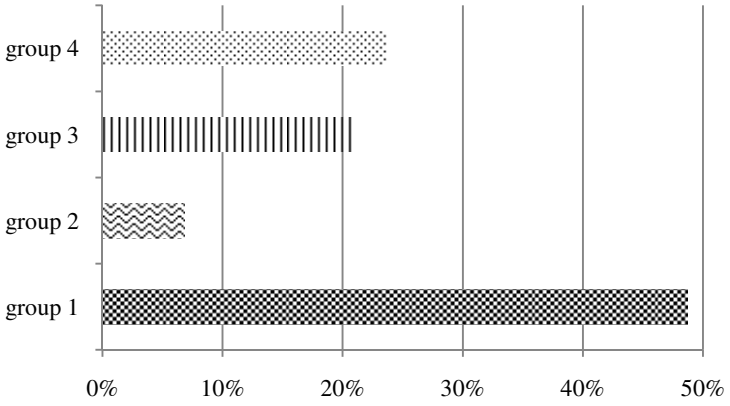

Fig. 2. Causes of actions leading to injury (Source: adapted from (Central Statistical Office, 2013))

The most numerous group of inappropriate condition of material agent (which was identified in 15651 cases) constituted constructional defects or inappropriate technical and ergonomic solutions of a material agent (48.7% of causes), faults of material agent (6.8% of causes), inadequate quality of the material agent manufacturing mainly failing to comply with required technical parameters or appliance of substitute materials (20.8% of causes in this group). A significant part of this group constituted causes linked to inappropriate exploitation of a material agent (23.6% of causes in this group). On the basis of these data it is possible to assess the size of the problem of faults leading to accidents. Moreover, it is worth to emphasize that in 2012 total cost of disability and family pensions, single compensations, sickness benefits, rehabilitation benefits (financial) and other benefits paid from accident budget of the Social Insurance Institution due to occupational disease, accidents at work, on the way to work and home was about 5.2 milliard zloty (PAP, 2013).

4 Conclusions

Huge complexity of production systems and their interaction with environment is clearly visible in modern industrial practices. Changing economical/economic conditions (European and global), in which Polish industrial companies also have to operate, are very demanding not only as far as quality is concerned but also modernity of production processes. Providing good working conditions is the determinant of these requirements. In order to achieve it, it is advisable to pay attention to a material agent and its faults which are crucial factors in industrial environment. As statistical data indicate they lead to almost 9% of accidents at work. Thus, their appropriate identification and diagnosis must be undertaken to reduce machine downtime and assure an appropriate safety level at work stands.

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