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Decomposition of electric machines with particular emphasis of the squirrel-cage induction motors

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Abstract. Most of the descriptions and definitions of systems are based on flow charts or block diagrams. Such representation generates difficulties related to the structure complexity. The basic obstacle arises from the fact of the arbitrary representation of elements with complex relationships. Each system can be, however, described by the graphical representation provided through diagraphs (so-called topological description). From the point of view of failure propagation, analyses based on undirected graphs are not useful. On the other hand, such notation allows for simplification of the definition and analysis of relationships of the subsystems. A more useful representation is formalized notation in the field of directed graphs, because it allows to determine the direction of propagation of failures between the subsystems and identification of structural dependencies (in the case of functional structures). In such case the author used the FMECA methodology assumes the participation of professionals, whose main task is to provide the assessment of the failure impact on system operation.

1. Introduction

The FMEA method (Failure Modes and Effects Analysis) found application in an identification of many features of industrial units (at stages of developing design concepts, estimation of functional characteristics that constitute basis of the operation and an identification of a detuning, failures or a damage) [3,19]. The FMECA (Failure Mode, Effects and Criticality Analysis) constitutes the next stage of a development of the FMEA methodology [1,2,4,5,6,10]. The FMECA was widened by analysis of the criticality, based on defined levels and occurrence possibilities of failures. The ordered way of determining interrelationships and the structural division are tools that greatly facilitate an analysis of the malfunction of technical devices, however, a notation in the form of block diagrams remains the dominating tendency. The traditional approach to the FMECA is a valuable source of information concerning the possibility of elimination of causes and potential consequences of an failures of technical measures, not only at the design stage, but also at the stage related to the operation of machines or processes.

Structural representation with the directed graph (developed at the angle of identification of different relations) allows for a simplification of procedures using computer data processing and elaboration of the dedicated tool cooperating with automation systems. In elaboration of the new (or adapting of existing) process data acquisition systems a special attention should be focused on [1,3,10,12]:

- requirements related to the architecture of the considered system referring to the equipment, machinery and accessories,

- physical configuration of data exchange subsystems (centralised or distributed),
- physical nature of measured values - sensors selection should take into account the nature of measured values (temperature, pressure, flow, displacement, presence etc.), equipment in network interfaces, an accuracy, method of measurement, calibration requirements and purchase of required instrumentation,
- availability of measured parameters - instrumentation of machines (lights, displays, signal columns) or decentralized (using industrial networks),
- optimization of control algorithms in terms of the minimal number of variables for control purposes and the identification of relationships between variables (examine the potential development of diagnostic rules).

2. Structural Decomposition of Electric Propulsion Systems

Generally, the structure of electrical propulsion systems may be analysed as combination of several functional elements [9,19,15,17,18]:

- Power Supply Lines,
- Control Unit (Frequency Inverters, Soft-starters, other equipment) [11],
- Actuator (AC Drive): stator windings, rotor windings, core lamination insulations, rolling bearings, shafts and sealing, brakes and cooling fans,
- driven units (external load or environmental factors influences).

According to the selected decomposition of the mechatronic drives takes the form shown in figure 1. In the method described in the article the structure of block diagrams was replaced by directed graphs representing relations between particular elements (due to the simplicity of implementation of searching algorithms).

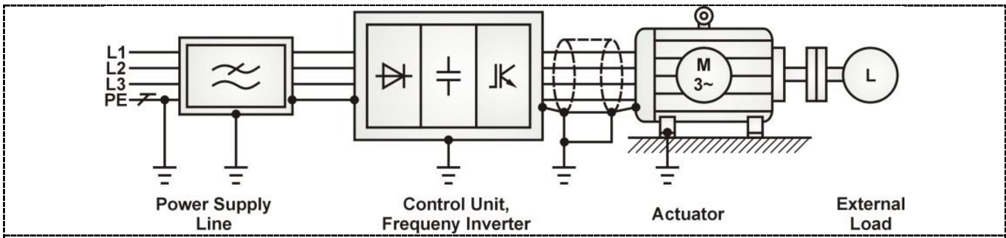

Figure 1. Main functional elements of electric propulsion systems.

To clearly define the procedure (in phases of determining functional relations) formalized outline of actions concerning the structure of the considered prediction system has been developed (figure 2).
The multilevel system decomposition refers to the hierarchical structure of considered technical agents or their groups taken as a whole. Additionally, none of the structures interfere with relations included in others alternative models, since they are based on completely different relations between their elements.
Division and manner of recording of relations between system components, in accordance with the FMECA methodology, is relatively obvious as well as results from rules applied for many years (figure 3a). Within distinguished structures, basic mechanical, electrical and control assemblies were combined together.
The presented method (figure 2b, 3b) allows for an elaboration of complex relations between elements, in the form of various structures, among other things:

- functional (in any degree of detail and a scope of specified structures) - possibility of checking the interrelation (e.g. assembly parameters in the form of power or the screwing moment) in the aspect of the correct cooperation of individual functional structures, determining assembly features, surface defects, etc.,

- information technology - a technical manner, direction and relations of dispatched signals,
- prognostic - the cause-and-effect graph containing basic components allowing the definition of the operational state classification (detuning, failure, breakdown), as well as interrelationships between individual states (edges defining connections in the form of the graph structure), quantitative character of considered transitions is determined with weights of individual edges.

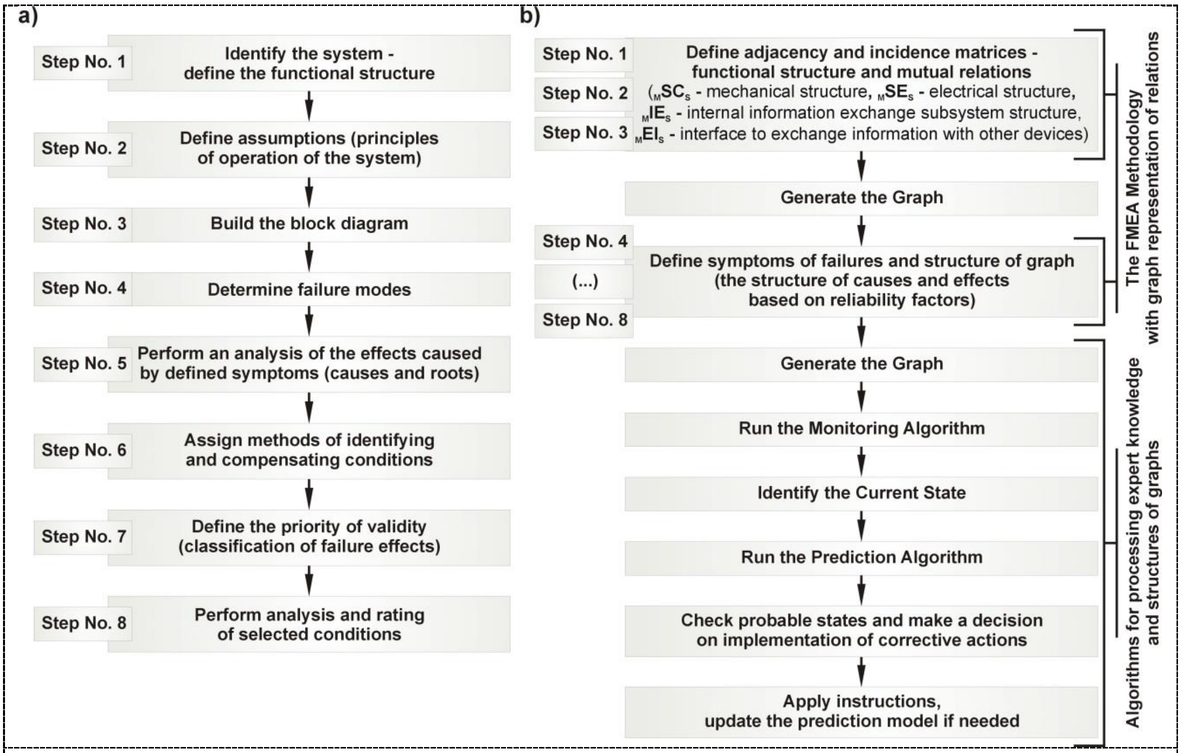

Figure 2. Block diagrams of: a) the FMECA methodology, b) steps necessary to execution in case of an elaboration of states prognosis (based on digraphs) and functional representation taking advantage of the matrix notation (consistent with the FMECA methodology) [7].

Decomposition structure is used, however, for the identification of failure states and paths of their propagation. A significant part of diagnostic information can be acquired on the basis of embedded algorithms used for self-diagnosis of frequency converters [9,11,17]. The classification of errors identified by the frequency converter allows for evaluating condition of many operational states, what increases the accuracy of diagnoses [17].

On the other hand, the research results and information collected from industrial applications indicate that most of the failures have mechanical or electrical natures [9,16,18,19]. Amplifying effects of development of detuning, failures, or damages are harmful interactions of temperature and abnormalities of rotor movements (malfunction of rolling bearings, shaft runout, imbalances etc.).

A versatility, a simplicity of implementation and modification of the method allow for a rapid and reliable identification of sources of irregularities as well as the failure paths and their impact to other parts of the machine. Selection of the level (in case of the structural analysis) was carried out to identify symptoms of wear (leading to the detuning, failures or damages) defined on the basis of historical data regarding duty of electric motors [8,9]. A key element is obtaining data related to the dependences between the development of the failures (within defined functional structure), the time and the range of their propagation.

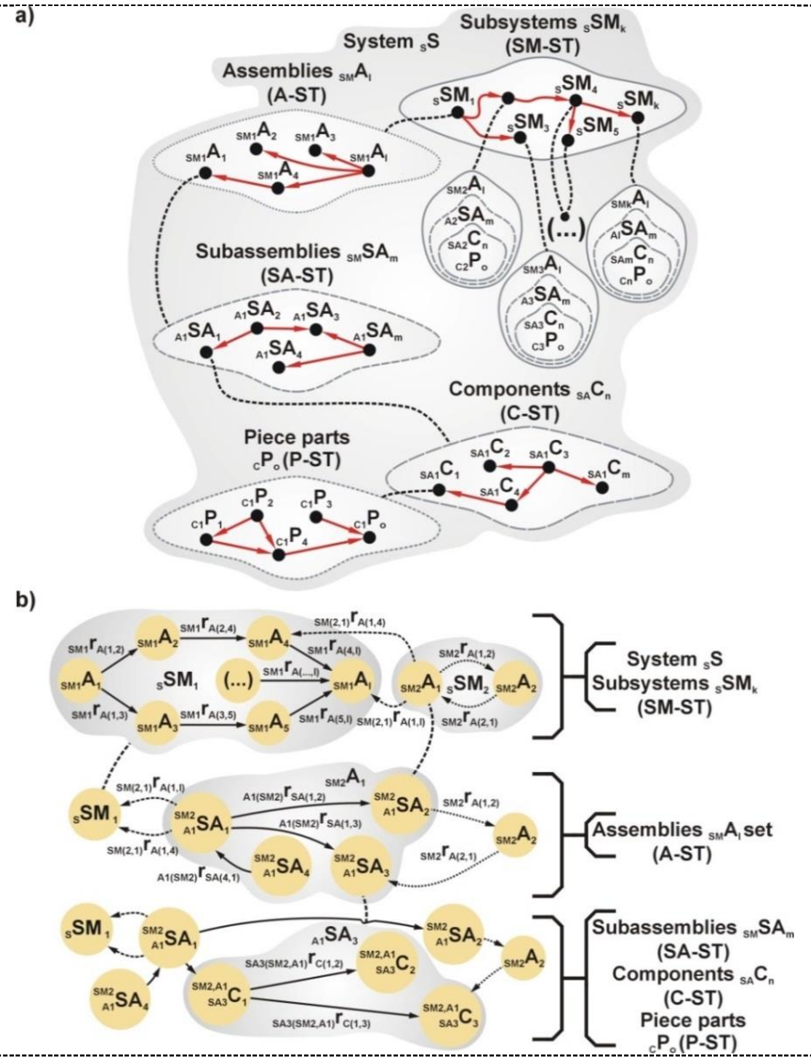

Figure 3. An analysis of the relationships complexity in case of mechatronic systems (functional separation): a) general view, b) structured view noted in graphs domain.

3. Aim of the structural decomposition of mechatronic drive systems

The basic assumption of decomposition of mutual component structures has been developed in order to identify the failures. The malfunctions can be classified to the following groups:

- mechanical - material losses, loss of cohesion, changes of shape and form of construction, mutual displacement of elements connected in a sustainable manner, increase of backlashes, deformations caused by excessive values of forces or moments, etc.,
- electrical - disturbances of power supply parameters,
- abnormalities of the applied technique of lubrication - losses of lubricant medium, contaminations (caused by the normal exploitation or by foreign particles), deficiency or excess of lubricant (after lubrication) etc.,
- hydraulic - phenomena occurring during flow of hydraulic fluids, including aeration, cavitation, turbulent flow,
- media flows - an identification of flow disturbances (liquids others than hydraulic fluids and gases),

- complex - perturbation of course of work resulting from the combination of irregularities classified in the other groups (secondary consequences of elementary damages).

Due to the adopted restrictions, functional subsystems of electric propulsion systems were divided into several independent structures (figure 4). Versatility, simplicity of implementation and modification of the method allow for a rapid and reliable identification of sources of irregularities as well as the failure paths and their impact to other parts of the considered machine.

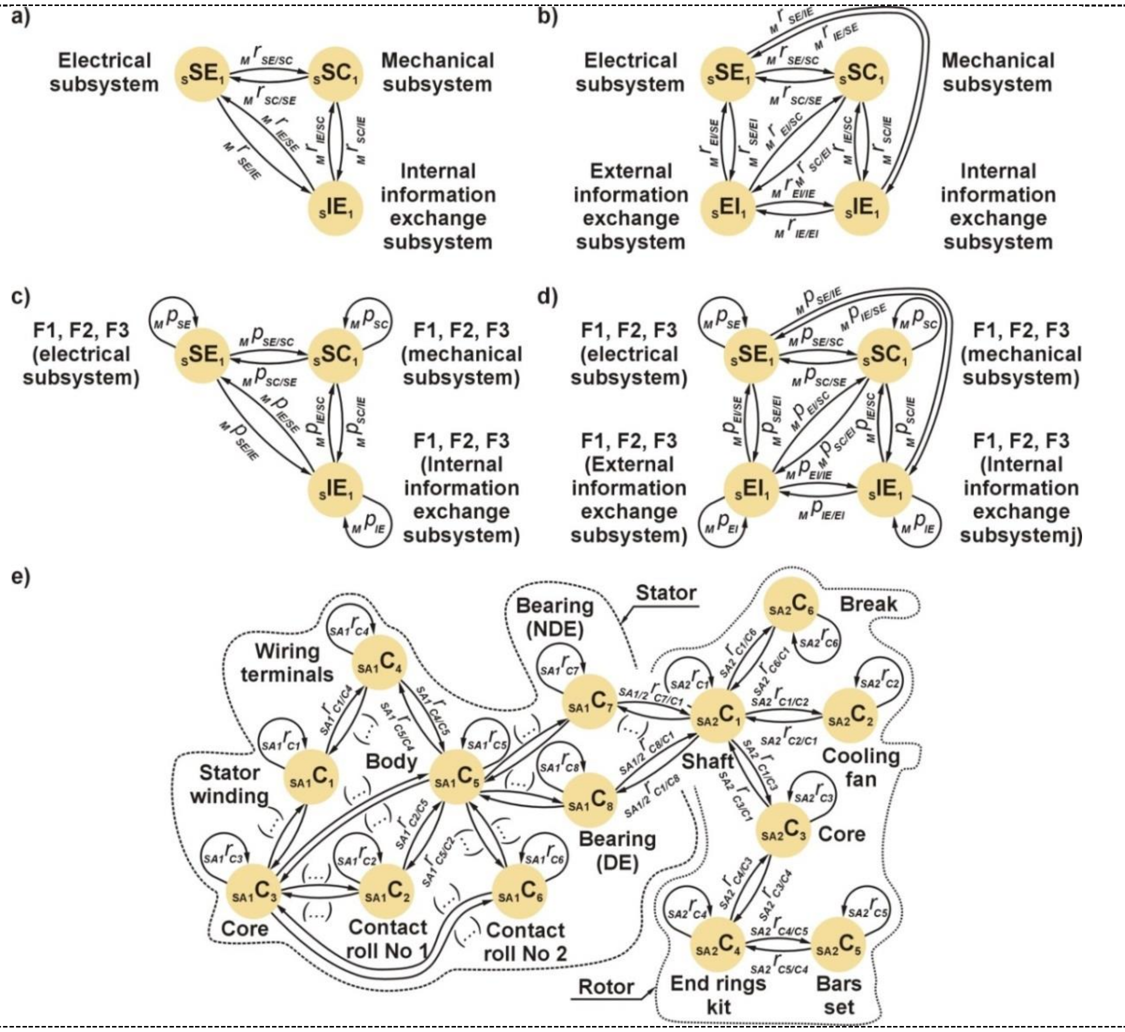

Figure 4. Graph of corresponding structures of the electric propulsion system: a) a structural form of dependences of stand-alone units, b) the structural form of distributed units, c) an interpretation related to the development of failures (stand-alone units), d) the interpretation related to the development of failures in case of distributed drives with network interfaces, e) the functional structure of the induction motor considered at the level of analysis realized on the basis of components, where: ${}_{S}SC_1$ - mechanical structure, ${}_{S}SE_1$ - electrical structure, ${}_{S}IE_1$ - internal subsystem information exchange structure, ${}_{S}EI_1$ - interface to exchange information with other devices of the system.

The functional structure of a squirrel-cage induction motor has been divided into two separate assemblies (a rotor and a stator; figure 4e) bonded with unequivocal relationships [9,13,14,18]. The failure analysis can be introduced at levels of specified assemblies or components, what is a sufficient degree of analysis for reliability forecasts and evaluation of the states.

4. Conclusions

The adaptation of described assumptions widened by the matrix data processing allows its use for identification of features of industrial facilities at stages related to the monitoring (especially of an operation, in assessment of the characteristics of processes, at stages connected to identification of formation and nature of errors and their consequences). The multilevel system decomposition refers to the hierarchical structure of considered technical agents or their groups taken as a whole. An identification of the driving element has been reduced to the system level. Such level of details enables also consideration of electric drives as a part of a larger set of technical system (consisting of a particular units with the possibility of linking of multiple drive subsystems in one coherent production system). An additional advantage is the ability to build the graph structure of the same system at different levels of functionality (or performance), and then connection of models into one consistent and comprehensive structure.

5. References

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