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APPLICATION OF MODULAR PROGRAMMING TO CHARACTERIZE OF FUNCTIONAL FEATURES OF THE LIMITED MECHANISMS OF COUPLING

Ivan Broshchak, Ihor Lutsiv, Ihor Hurey

S u m m a r y

The paper deals with the analysis of limited mechanisms construction designs exemplifying modern restricted couplings of world leading manufacturers. The description of limited mechanism structure as a technical system is given on the base of functional approach. The possibility of limited mechanisms separation into individual modules on the functional principle is proved. Main internal and external links between the elements of the technical system of limited mechanism are analyzed. These elements are proposed to be regarded as individual modules with the certain functions, characteristics and criteria.

Keywords: limited mechanism, modular design, distributing module, transmission module, accumulation module, energy flow

Zastosowanie programu symulacji modułowej w procesie analizy charakterystyki sprzęgieł przeciążeniowych uwzględniającej ich właściwości funkcjonalne

S t r e s z c z e n i e

W pracy przedstawiono modele nowoczesnych ograniczających mechanizmów konstrukcyjnych na przykładzie sprzęgieł przeciążeniowych dostarczonych od wytwórców. Wykonano analizę charakterystyki badanych sprzęgieł uwzględniającą ich właściwości funkcjonalne. Stwierdzono możliwość zastosowania metody prowadzenia procesu projektowania poszczególnych mechanizmów konstrukcji sprzęgieł na podstawie analizy dostępnych modułów opracowanego programu. Stwierdzono przydatność wszystkich składowych programu symulacji numerycznej na podstawie zdefiniowanych przez użytkownika kryteriów funkcjonalnych, parametrów oraz wymagań konstrukcyjnych.

Słowa kluczowe: mechanizm ograniczający, konstrukcja modułowa, moduł dystrybucji, moduł transmisji, moduł akumulacji, przepływ energii

Address: Prof. Ihor LUTSIV, Ivan BROSHCHAK, PhD Eng., Ternopil National Technical University, Faculty of Mechanical Engineering and Food Technology, 56 Ruska St., 46001 Ternopil, Ukraine, e-mail address: i.broshchak@gmail.com, lootsiv@tu.edu.te.ua; Prof. Ihor HUREY, Rzeszow University of Technology, Faculty of Mechanical Engineering and Aeronautics, 12 Powstancow Warszawy Av., 35-959 Rzeszow, Poland, e-mail: ihurey@prz.edu.pl

1. Formulation of the problem

Today the design process of new technical objects as well as the modernization of the existing ones demands new approaches that must meet the development of IT techniques and should be based on the fundamental principles. That is coupled with the technical progress development and prevalence of IT and computer technologies the demands to the quality characteristics of mechanisms for different purposes come to the forefront of main operating requirements for technical objects. The machines high quality providing is based on the quality of the corresponding elements as well as on their quantity minimization and reduction of inter-element links. The modular approach to the design of machines and limited mechanisms in particular is one of the perspective directions of the required quality parameters providing. This is because the operating characteristics of modules separated by the main function and unified modules are much more amenable to formalization and experimental simulation. This in turn opens the possibility of providing of machine high optimal quality operating characteristics.

2. Analysis of previous research

The machine design needs to create the scientific approach to evaluate the technical level and possible competitiveness of mechanisms with variety purposes of function [1-3]. The problems of machine and mechanisms optimal design as well as their multi parameter synthesis are of actual importance [2-4] The above mentioned research comprises certain different elements of the traditional approach assuring the machine quality characteristics. In this way the design object is considered as an element determined beforehand in constructive design and operation function: for example an overload clutch, a tool-holder for thread cutting, and so on [5-10].

Basing on the developed algorithms and methods of multi criteria structural and parameter synthesis of machinery [3] it is possible to form the new approach of limited mechanisms design. As this statement indicates such approach is to be based on the modular design principle [1].

As a result of machine modular constructive design research [1] new effective techniques came to hand regarding design and optimization of machine main operational characteristics [3, 4].

3. Limited mechanism (LM) structure modular design

In order to develop main approaches to the limited mechanism (LM) structure modular design, it is necessary to define its modular hierarchy as a technical system as well as to determine main system elements and to select its

general, basic and additive functions. On the base of functional correlations of the LM technical system elements, it is needed to determine the main functional and construction modules and basic principles of their composition.

Creating of the new LM is based on the using experience of its typical representatives in a form of different kind over-load couplings, chucks and other limited devices that have certain function parameters. The aim of the new LM technical system creation stands in the improving of its main quality indicators (operation characteristics) as well as in developing of the design process itself. In this way the design process and the process of improving of main LM operation characteristics are to be considered in the ranks of the integrated single system. Hereby main LM operation characteristics are to be determined by the main quality criteria of limited mechanism as a technical system.

The LM operation exemplifying by the overload couplings (Fig. 1) is based on the principle of the torsion torque value limiting using kinematic pair and elastic element. In turn the elastic element performs as a regulator of the torsion torque value, being transmitted through the LM.

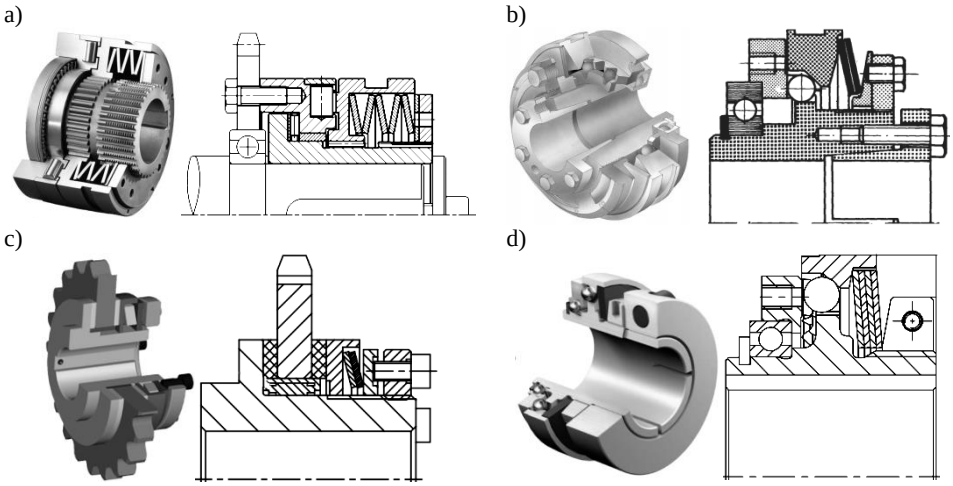


Fig. 1. Analysis of the LM construction designs exemplifying by the overload couplings: a) roller overload clutch "SIKUMAT SN" (RINGSPANN GmbH) [10], b) synchronous clutch "EAS-NC" (Mayr) [8]; c) friction torque limiter "RUFLEX" (KTR) [6], d) ball torque limiter "SYNTEX-NC" (KTR) [7]

When defining the main operation elements of the LM technical system it is necessary to pay attention to the basic prognostication and creation frame model of the new technical systems in a form of LM (Fig. 2).

Let us examine the above mentioned frame model together with taking into consideration the main elements of the given system and its functional interlinks. In regard to the given operation principle the LM construction design features

are implemented now by a certain set of engineering decisions (using cams, balls, rollers, etc). In this way, generalizing this idea, we can distinguish the next technical system groups of elements: 1) accumulating (A) (elastic) element; 2) energy transferring (T) element; 3) energy distribution (S) elements (Fig. 2).

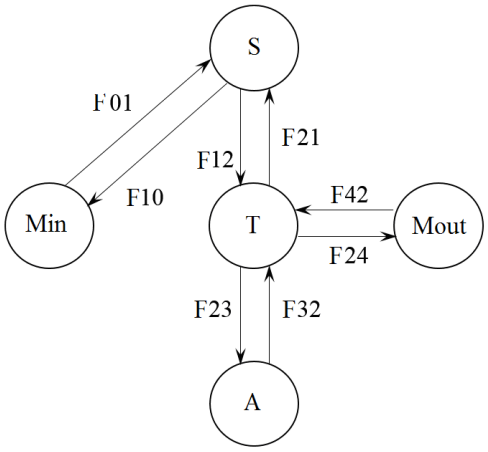


Fig. 2. Generalized functional model
of the LM technical system

The LM operation principle can be described as follows: the drive energy M_{in} is transmitted through the power flow F01 to the distribution module S. Then energy through the power flow F12 is transferred to the transmission module T. Further the next two energy flows F23 and F24 go to the accumulating module A and to the external surrounding M_{out} (toward machine). Wherein the corresponding opposite flows F10, F21, F32, F42 operate (Fig. 2).

The LM technical system hierarchy of elements placement is based on the functional distribution principle. In this way each element as a part of the LM technical system inherents its basic functions. That is the given consecution of the LM modulus hierarchy and the interlink system of the main system modules parameters in particular it is based on the sequence of the energy transferring and distributing: after the energy division at the first stage the energy quantity extracted by the absorbed module and the quantity of the usable energy transmitted to the mechanical system first of all depends from the second transmission module.

The first level in the LM modulus hierarchy structure belongs to the distributing (distribution-transmission) module. This module consists of such elements as working surfaces and working members. The working members consist of movable and non movable bodies of different kind with a given geometric shape to transmit energy (cams, balls, rollers). The working surfaces

are being thought the surfaces that directly contact with the working members or belong to them (cam surfaces, ball holes, grooves). The given module main task (function) is to divide the energy more precisely into the useful and excess energy as well as its effective transmission.

The transmission elements transferring two kinds of energy (useful energy and excess energy) can be classified to the second level of LM modulus hierarchy. These elements transmit energy in the determinate directions: useful energy – to the mechanical system kinematic chain and excess energy – to the accumulating element.

The accumulating module is the third LM level. The main function of this module is to provide system with nominal energy and to absorb the excess energy.

The forth LM modulus hierarchy considers LM as a source of energy initiation that affects the LM operation. Weight-and-dimensional characteristics are the priority factors that are to be considered at the forth LM level.

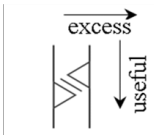
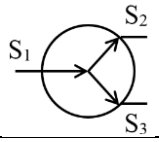
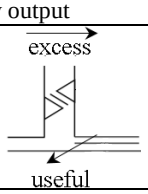
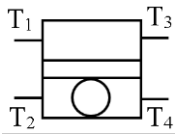
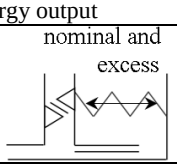
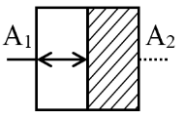
Basing on the main functions of the corresponding LM functional modules it is possible to identify their input and output energy flows (Table 1). In this way the existence of single input energy flow and double output energy flows comprises the distributing (distribution and transmission) module. Most of all in regard to the function of input flow S_1 we have to do with the energy flow that comes from the environment (machine drive) and is to be restricted. The excess energy flow S_2 is one of the distributing module output flows. This energy is separated by the given module and most of all is directed to the accumulating module. The flow S_3 of the useful energy is another output flow of the distributing module. It is directed to the TS LM environment (to the machine operation element).

The transmission module is represented by the movable joints in the form of key or spline connection as well as another coupling and serves most of all to the energy flow transfer from the distributing module to the accumulating module and to the LM environment. First and outmost the given module is characterized by two inputs T_1, T_2 and two outputs T_3 and T_4. The transmission input T_1 and the output T_3 correspondingly act to the excess energy from the distributing to the accumulating module. The inputs T_2 and the output T_4 correspondingly serve to receive-transmit of the useful energy from the distributing module to the LM environment. In a case of the transmission module absence the distributing module represents the dividing energy into the useful and excess components largely as a result of friction forces and transmitting them (friction-type overload coupling).

The accumulating module is used in LM to accumulate the nominal and excess energy and is characterized mainly by the presence of the A_1 input/output through which the excess energy flow from the distributing and transmission modules is going. The given module also has the actual input A_2 which is used to the useful energy setting for the LM operation and in a case of external energy

flows acting. The above noted effect regards to the operation of the LM accumulating module as a damping device.

Table 1. Main flows of energy determination and LM basic modules symbolic notation

Module title	**Main function (purpose)**	**Energy flow distribution diagram**	**Symbolic notation**
Distributing (distribution and transmission)	Input energy flow distribution into useful and excess energy and their transfer		
Description of distributing module inputs and outputs	S_1 – distributing module input, mostly is characterized by energy flow directed from TS LM environment; S_2 – distributing module excess energy output and input of nominal energy (mostly from accumulating module, in many cases through the transmission module); S_3 – distributing module useful energy output		
Transmission	Excess and useful energy flows transfer		
Description of transmission module inputs and outputs	T_1 – transmission module input, mostly is characterized by energy flow of excess energy directed from LM distributing module; T_2 – transmission module input, mostly is characterized by energy flow of useful energy directed from LM distributing module; T_3 – transmission module excess energy output and input of nominal energy (mostly from accumulating module); T_4 – transmission module useful energy output		
Accumulating	Accumulating of nominal (initialization of operation starting conditions) and excess energy		
Description of accumulating module inputs and outputs	A_1 – accumulating module input/ output, mostly is characterized by energy flow of excess and nominal energy; A_2 – additional input/ output of nominal and excess energy, which is used to initialize LM operation nominal energy; available in case of double-type action on the accumulating module.		

The LM synthesis is based on the possible variants of their constructive designs existence. These designs appear in the process of optimization of their elements interlinks according to the certain criteria. The LM modulus structure theory verification as well as forming of the main approaches to the new LM synthesis can be provided by analyzing of TS LM elements interlinks

exemplifying by the well known and effective modern constructive designs (Table 2).

To optimize the investigated LM and the similar mechanisms in regard to their modulus design process it is necessary to research the certain determined array of main external and internal links of the basic elements. This array can be derived in a form of:

$$\begin{cases} R_{out} = S_{Rout} \cup T_{Rout} \cup A_{Rout} \\ R_{in} = S_{Rin} \cup T_{Rin} \cup A_{Rin} \end{cases}, \quad (1)$$

in which S_{Rout}, T_{Rout}, A_{Rout} are the interactions of the distributing, transmission and accumulating modules of the TS LM correspondently; S_{Rin}, T_{Rin}, A_{Rin} are the internal elements interactions of the distributing, transmission and accumulating modules of the TS LM correspondently.

Examining the constructive design and the operation principle of the roller overload clutch "SIKUMAT SN" by the RINGSPANN GmbH firm (Table 2) it is possible to observe the appearance of the corresponding elements of classical structure. They are the distributing S, the transmission T and the accumulating A systems. Exemplifying the roller overload clutch "SIKUMAT SN" according to

Table 2. Forming of LM synthesis main approach based on the basic modules interlinks analysis

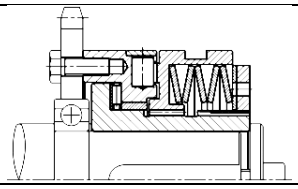
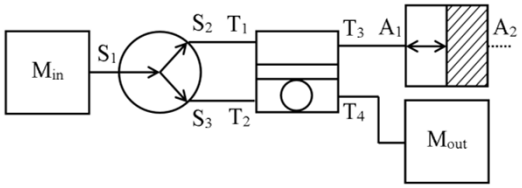
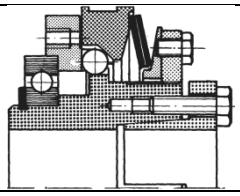
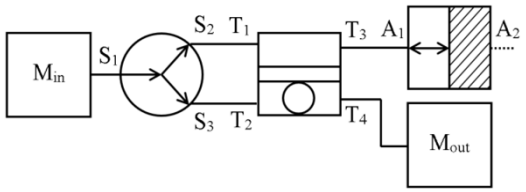
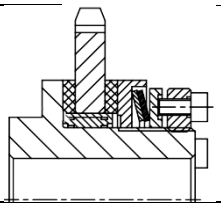
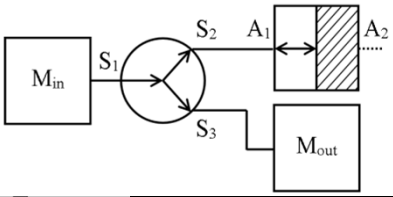
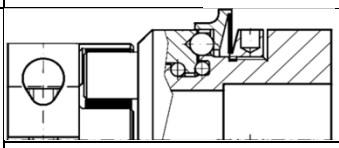
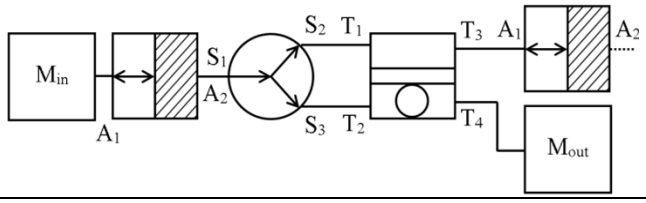
Title	LM design	Characteristics
Roller overload clutch "SIKUMAT SN" (RINGSPANN GmbH) [10]		Availability of separate distributing, transmission and accumulating modules
	Modular principle diagram	
		

Table 2. Forming of LM synthesis main approach based on the basic modules interlinks analysis

Title	LM design	Characteristics
Synchronous clutch "EAS-NC" (Mayr) [8]		Absolute combination of distributing and transmission modules. Absence of separate transmission module
	Modular principle diagram	
		
Friction torque limiter "RUFLEX" (KTR) [6]		Absence of transmission module
	Modular principle diagram	
		
Backlash free torque limiter "ES-2" (R+W) [9]		Availability of damper
	Modular principle diagram	
		

the structural scheme of the module design each of the TS elements can be characterized as:

$$M_{in} \leftrightarrow S_1\text{-}S_2 \leftrightarrow T_1\text{-}T_3 \leftrightarrow A_1\text{-}A_2$$
$$M_{in} \leftrightarrow S_1\text{-}S_3 \leftrightarrow T_2\text{-}T_4 \leftrightarrow M_{out} \quad (2)$$

in which M_{in}, M_{out} are the input and output of LM technical system.

The LM machine interlinks are defined as the LM energy input ($M_{in} \leftrightarrow S_1$) and output ($T_4 \leftrightarrow M_{out}$). In this case the useful and the excess energy presence at the input but only the useful energy at the output. Such energy flow restriction takes place due to the dividing energy in the distributing module into the useful and excess energy. In this position two separate energy flows appear: the useful energy flow ($S_3 \leftrightarrow T_2\text{-}T_4 \leftrightarrow M_{out}$) and the excess energy flow ($S_2 \leftrightarrow T_1\text{-}T_3 \leftrightarrow A_1\text{-}A_2$). In its turn due to the flow $T_3 \leftrightarrow A_1$ the excess energy is accumulated in the accumulating module.

Each of the LM modules is characterized by the certain number of inputs and outputs.

In this way the distributing module *S* possesses three channels S_1,S_2,S_3. The S_1 channel serves to the entry input of the LM energy flow. The S_2 and S_3 channels belong to the excess and useful energy correspondingly.

The transmission module is characterized by four connection channels. The channels T_1-T_3 correspond to the useful energy input and output and the T_2-T_4 to the output.

The accumulating module is characterized by the single A_1 main channel and the other A_2 in addition. The A_1 main channel is used to the excess energy transfer from the distributing to the transmission module. The A_2 addition channel is used to the setting to the accumulating module the nominal energy for the LM operation.

The array of the LM "SIKUMAT SN" main modules external and internal links can be represented in the following form:

$$\begin{gathered} S_{Rout} = M_{in} \leftrightarrow S_1 \cup S_2 \leftrightarrow T_1 \cup S_3 \leftrightarrow T_2 \\ T_{Rout} = S_2 \leftrightarrow T_1 \cup S_3 \leftrightarrow T_2 \cup T_3 \leftrightarrow A_1 \cup T_4 \leftrightarrow M_{out} \\ A_{Rout} = T_3 \leftrightarrow A_1 \\ S_{Rin} = S_1 \leftrightarrow S_2 \cup S_1 \leftrightarrow S_3; \\ T_{Rin} = T_1 \leftrightarrow T_3 \cup T_1 \leftrightarrow T_4 \cup T_2 \leftrightarrow T_3 \cup T_2 \leftrightarrow T_4; \\ A_{Rin} = A_1 \leftrightarrow A_2 \end{gathered} \quad (3)$$

It is possible in the given characteristic of the *TS* LM array of elements and links to define the external and internal links. In this way the links between

modules belong to the external modulus links $M_{in} \leftrightarrow S_1$; $S_2 \leftrightarrow T_1$; $S_3 \leftrightarrow T_2$ and others. The module interlinks that finally are the correlation of the input and output energy flows at the certain module channels can be regarded to the internal module links. As an example $T_1 \leftrightarrow T_3$; $T_1 \leftrightarrow T_4$; $T_2 \leftrightarrow T_3$; $T_2 \leftrightarrow T_4$. are such correlations for the transmission module .

LM main modules external and internal interlinks research is based on the exploring optimal value criteria providing the main functions operating. In this way each of the modules interlinks is characterized by the certain criteria. Optimizing the array of the *TS* LM external and internal modules interlinks it is possible to receive new high effective LM constructive designs.

The given LM design approach considered to be used as a base for creating of new technical system design methods in regard with their quality characteristics.

4. Conclusions

The possibility of limited mechanisms design dividing into the separate modules regarding their operational principle is proved. Basing the optimization of the separate modules external and internal interlinks the given approach allows to receive new high effective LM constructive designs regarding their quality characteristics.

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