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Review Article

Medical and Biological Sciences to the Question of Structural Identification of the Synovial Model Joint

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Abstract

A review of general approaches to modelling the function of the synovial joint by the example of the knee the joint. The assessment of the structure and function of the synovial joint is considered within the framework of generally accepted concepts. The applicability limits of existing models in engineering and medicine are evaluated. Assumptions are made regarding the wave nature of the mechanical interaction in a pair of biological tribo-conjugation conception of the articular joint as a complex oscillatory system with nonlinear dissipation Condition. There is a need for an interdisciplinary approach to the description of the articular joint as a transmission unit in the elastically deformable multi-link mechanical system, endowed with a locomotor function of the wave nature.

Keywords: *Tribology of the Synovial Joint, Transmission Mechanisms, Model Identification, Biomechanics Nickname, Biotechnology*

Introduction

In the sixth edition of his course in theoretical mechanics, published in 1956, academician A.I. Nekrasov decrees It leads to a conditional, to a certain extent, separation of ki on statics, kinematics and dynamics, noting complexity and the ambiguity of the teaching sequence [22]. Mechanics of highly integrated self-organizing living systems all the more demonstrates such a convention. The principle of the unity of structure and function, noted by I.P. Pavlov in the description of the device of higher nervous activity in living nature as a whole reflects continuously a tremendous evolutionary process, whose being among others are locomotor adaptation, as a result of entropy [32]. Applied to system mechanics organs of support and movement, namely to the device of joints human body, this remark applies fully in questions of kinematics, dynamics and, with some lag, statics 1 are considered in the context of material and non- discontinuous patterns and relationships.

The relevance of the model approach to the description of the joints of the human body is associated with necessary things.

The ability to solve the following problems of technology and medicine:

- Development of design specifications endoprostheses of joints that differ in function total invariance of the structure of living and reflecting uniquely identified personification parameters [29,40,51].

- Diagnosis and prediction of condition and of locomotor function in medicine and sports those [16,35].
- Development of design specifications bioreactors designed to create and cultivation of tissue structures for bio- engineering replacement of articular and other complex defects [34,42].
- Development of technical specifications for the development of automatized control systems and optimized locomotor function in medicine, sports and technique [21,26].
- Identification of the inertial mass model of the body human and biological tribo-conjugation models for use in technology in view of the effective controlled energy transfer observed in living mechanical systems [11,20].

Hypothesis of a flat mechanism with a lower a couple

Description of the kinematics of the joints is widely Leno in modern printing thanks to the development of systems one Statics, as a branch of mechanics, studies a special case of dynamics, when the results of forces acting on the body mutually destroy Xia. For the purpose of terminological clarification, it should be noted that statokinetic vestibular function studied in the course of otitis three, reflects the mechanisms controlling the balance of the body, as inert mechanical system, only partially touching the static equilibrium of its individual links. endoprosthetics in orthopedics, analysis of gait in Rehabilitation and sports, the need for bioengineering, robotics and computer industry. General that substantial part of kinematic research is a consideration of movable bone joints in the framework of a flat model - a hinge, as evidenced by is the setting of tasks in the form of a localization search rotation axes and their trajectories. Look significant reasoning about instant search paths axis of rotation (DOM) in the knee joint, the beginning of which to a certain extent, in 1973, the Eye laid GL Smidt, in his work "Biomechanical Analysis flexion and extension in the knee joint" [50]. Will circumstances at the same time in arthroplasty joints the concept of low friction was introduced "metal-polyethylene" friction pairs, which caused the interest of researchers in the biomechanics of the knee joint in connection with encouraging early results - endoprosthetics.

In 1982, by the time out distant and not so unambiguous results prosthetics, the work of M. Panjabi with co-authors [47] with an analysis of the methods of searching for axes of rotation knee joints, known at that time, in the methods for obtaining data and errors inevitable in evaluating a joint as flat connections. Eleven years later, work A. Hollister., *et al.* [41] where, rather critically speaking out on existing methods to lawsuit of rotation axes and referring to the work of M. Panjabi, the authors again conclude that the flat motion divisions to assess knee function. In 2005 and 2015 A.V. Borisov from Tula State University consistently Candidate [3] and doctoral [4] dissertations in which the author by modeling the dynamics of many link anthropomorphic mechanical systems showed limitations of a flat model due to the need taking into account the reversible deformation of the skeleton as a space- natural phenomenon.

However, the current generally accepted the chain of description of movement in joints is poly-centric rotation around the instantaneous axis of rotation, having a predetermined displacement trajectory in three plane Sty. For the sagittal section of the knee, example, a flat curve having the "shape comma" [14,19,20]. In view of the rich phenomenology (su- significant differences in the localization and direction of the axes rotation recorded during isolated traffic niyah thigh and lower leg) some authors suggest biaxial motion chain, since objectively mismatch of the trajectories of the instantaneous axis is recorded rotation during flexion and extension in the knee joint [43,49].

Medical and biological sciences spatial mechanism hypothesis with top pair

As you expand your arsenal of search methods for MOB the phenomenon of deformation and vibrations of soft tissue, which, according to some authors, significantly and harmful deviations in the obtained results [37,48,49,54], which required the development of an entire system measures to take them into account and ways to correct the limit allowed in error measurements, including neural network algorithms statistical analysis of the movement of a body segment, specifying registering parameters of bone movement [36]. Summarizing

approaches to the study of motion, B. Chen with [38] describe two modelling concepts knee joint - anatomical and phenomenological and the phenomenological authors reject low information content and an assessment of the parameters of the MOB according to the anatomical concept is carried out on the basis of newer than the projections of the motion of the axis of rotation on the plane of the straight angular coordinate system in three-dimensional space. It is significant that, studying the features of elastic finite element response load authors faced with the nonlinearity of this process, but considered this fact is not clinically significant. Interesting in this regard is the work M.L. Ioffe [13], in which the number of degrees her freedom for flat movement in the knee joint in the sagittal plane in a model absolutely solid body. Calculations showed that under the condition of inextensibility cruciate ligaments of the knee joint degrees there is no baud in the system. Assumption of the extensibility of both cre- of stasiform ligaments gives a flat system immediately two degrees of freedom, the extensibility of one of the cross the ligaments retains only one degree of freedom. From observations and studies, it is known that the supporting and auxiliary elements of the joint are absolutely solid - are not, which is also shown in the study of mics of a multilink anthropomorphic mechanism [3]. Him author, already mentioned A.V. Borisov, also concludes on the inadequacy of the absolutely rigid body model for tissues joint and indicates the need to account for deformation, as a spatial phenomenon because the description flat type of motion in joints, as models of inter action of absolutely solids, substantially coarsens motion model. The task of identifying a model under uncertain conditions one of the most difficult tasks of analytic mechanics and is, in many ways, a matter of intuition [15], in connection with which, the probable cause of the ambiguous results and errors in the study of kinematics stavas and biomechanics in general, could become a false intuition.

The active message is that, firstly, without sufficient justification, a flat del movement and secondly, measured parameters were angles - scalar quantities that are not vectors of finite displacement [30]. Measurable in degrees, the final rotation angles described in formulated works are scalar quantities, that is, the result of adding the measured angles is also a scalar quantity. Final angular displacement Paschenie is a vector quantity, measured in radians, resulting in the addition of finite angular displacements carried out by the rule of addition of vectors and is by vector. Thus, a probable error becomes substitution of the concept of a physical phenomenon (finite angle the displacement, measured in dimensionless quantities - radians) by a physical quantity (final angle of rotation company, measured in degrees).

The essence of the concept substitution error is the absence of the commutativity property of the sum of scalar quantities in vector space, which means necessary the necessity of introducing complex variables in order to descriptions of trajectories of movements of the articular ends bones, as evidenced by modern work, example [44,53,54] and authors of classical literature on biomechanics [12]. It seems, however, that the instrument analysis of angular displacements and trajectories in three studies have been applied with significant limitations: in [54], for example, angles of movement of the articular ends of the bones on an autopsy material, which implies a conventional interpretation of results for living people; in article [53] authors analyze the "pure" bending/unbending angles, denia/casts and rotations, measured in degrees, without relative to the trajectories of movement of the articular ends bones. In [44], joint joints represent. They are in the form of spherical joints and the results are reproducible in computer models for games and graphic installations. The results of these and other studies appear to be also indicated the need for development inertial mass simulation of multi-link mechanical system of the human body as a generalization inertial navigation methodology in biomechanics for estimates of autonomous movement in space.

Some aspects of friction dynamics in joint

Objectively recorded and requiring accounting in models of articular connection, the phenomenon is effective control of friction due to reversible phase transition of joint fluid from a viscous state to elastic, observed experimentally at angular shear rates of the order of 10 2 rad/s and in a given range not temperatures [11,20]. Joint fluid is an elm which, with a free steady flow, exhibits pseudoplastic properties. It can be assumed, that synovial fluid pseudoplasticity is at the time of unloading, for example, in the transfer phase limbs when walking. When loading, in phase axial load, increasing force and angular shear rate [27,31] and the phase state of the liquid changes to elastic, in which the phenomena of dissipation are weakly manifested: no direct contact between the rubbing surfaces, providing the transmission of moment of force between the articulated joint ends of the bones.

The relaxation time of the SG in relation to the period of oscillation there are few articulating segments of the body, which Flexibility and precision in transfer management kinetic energy in the junction. Periodic changes in the phases of rest and slip are known on in technology as dynamic jamming in wide braking systems mechanisms [8,9,24] with efficiency coefficients actions reaching 0.9-0.95. In such systems, there are brake modes under which the steady motion of both leading drives is given links and traction modes with unsteady or steady-state non-equilibrium movement of the drives. In the braking mode, a significant transmission of cops from one link to another does not occur 2, which can be put the phase of limb transfer while walking.

Traction the mode is thus mapped to the loading phase, when the external resistance (in this case actions of support and inertia) upsets the balance of motion drives. Drives in this model using the example of knee joint should be considered femoral and tibial bones moved by mutually crossing between muscle segments. In the monograph [8] the possibility of self-braking for any board transfer moments. Prerequisite this effect is the pairing of active drives: in the case of the knee, this condition is satisfied, since the muscles are attached crosswise: from the tibia to the tibia and from the tibia to femoral 3. Therefore, the model of the synovial joint, as tribo-conjugation, it is possible to consider in the form of frictional self-oscillating system. As a source the kinetic energy in it is muscle contractions joints leading to oscillatory motion segments of the skeleton. Oscillating tribo system 2.

The cruciate ligaments of the knee provide transverse exchange contact of the external and internal condyles of the femoral and tibia in different phases of the step. Probably such the interaction of the articular ends of bones endowed with a special geome-three, we can define how the spin-orbit interaction Frenet chain kinematic reactions describing normal torsion of the trajectories of the system components during their interactions action. 3 In the general case, all articular joints satisfy this condition. skeleton unity. Van mating surfaces during phase changes rest and slip and appears as a regulatory link characterization of the connection of articular surfaces in the process cyclic phase change of the articular fluid bones from viscous to elastic. Nonlinearity Ki restoring force is determined by the properties of articular cartilage, bone elasticity and auxiliary apparatus of the joint [31].

Some aspects of dynamic stability of support segments

The need to take into account the inertial properties of the segment. This body leads to consideration of the connection model supporting segments of limbs as conjugated returned pendulums. In this case, the muscles leading in the movement of the articular ends of the bones, play the role of para- metric pathogens in the above-described oscillator no system. Evidence of the legitimacy of this conclusion are works [45,46], which show the role of fast (with small amplitudes and high often tami) and slow (with large amplitudes and small frequencies) of movements depending on the characteristics of the wheel muscle bones as control factors of postural go balance and movement control. Inertial attached great importance to the properties of the human body Professor A.N. Bernstein, who described in his books locomotor function as a multi-level process discrete control of continuous “ballistic “movements” [2].

Probably about the same phenomena. writes E.I. Butikov in his works [5-7], describing the role oscillations of low and high frequencies at numerous stabilization modes. It is noteworthy that in the description properties of an inverted pendulum, the author discovers dynamic chaos, which is consistent with the result- recently conducted by M. Georgescu., *et al*. following the dynamics of movement in the knee joint [39,52]. If we accept the dynamic jamming hypothesis in self-braking systems as a control method friction in the joint, it is useful to describe this process the widely studied theoretical models of coupled oscillators with nonlinear dissipa- describing stable chaotic and quasi- periodic behaviour of some dynamical systems [17,18]. Such a theoretical approach makes it possible take into account frequencies, amplitudes, phases and other properties studied vibrations, significantly expanding the arsenal cognitive tools of highly integrated living mechanical systems.

For all its beauty and courage, there are many granularity of dynamic chaos, significant the accuracy of the measurements included in studied systems, the effect of noise, a small number of known real systems identified as random mental, make you think about the need

for thorough testing hypotheses describing the dynamics of interaction in articular joint, as structurally stable chaotically functional function. Confirmation of this hypothesis, however, would create a wide field of possibilities for theoretical search for patterns inherent in morphogenesis in the broadest understanding of this process [10,14].

Concept and technical solutions in joint joint modeling

A relatively simple external mechanical device the quality and apparent evidence of joint function, Apparently, they caused stability common mental construct which is perceptible in the perception of a joint as kinematic swivel interchanges with sliding friction. From the standpoint of evolutionary development living mechanical systems such an inference is there is a hidden inner contradiction consisting in the assumption of energy losses, folding, with one sides of unjustified friction losses in the hinge, with which is an active scientific struggle and on the other hand energy losses for stabilization of an unstable link system as a result of achieving low Niya.

Thus, we can formulate the technical contradiction of the joint model as a joint with friction slip: friction should not be to conserve energy gii on the movement of the body and friction should be great to control and maintain body position. The solution is what kind of contradictions are widely described in the inventor- literature: the friction system should be dynamically physical and manageable by changing the scale of interaction in it, which is observed phenomenologically and shown in studies. Interactions of bone macrostructures is provided by a phase change of the state of high molecular weight tribocompositions - synovial fluid. Living continuous and continuous systems the pressure of evolutionary selection, no doubt successfully solved this problem, formulated as " "effective energy transfer" as a means of eliminating this technical contradiction by acquiring niya special adaptation - synovial joint, as gear mechanism.

This reasoning allows us to consider the mechanisms already known from technology, taking into account the inertia ononic properties, anatomical and biomechanical device joints and the evolutionary feasibility of high coefficient of performance and variability of adequate relationships. This class of mechanisms is inertial pulsed continuously variable transmissions with elastic link. Among these mechanisms, the device stavov most satisfy inertia- stepless gears without mechanisms of free the course characterized by reliability, compactness, high efficiency and a wide range of transformation moment in response to a changing load as ny and in the direction [1]. According to its design specific features, such mechanisms turn out to be useful in conditions where the process performed in any direction of movement, for example measures, cyclic movement of the supporting segments of the irregularities when walking.

In gears containing component, unlimited rotation the intermediate shaft is structurally absent and the shaft hesitates. Intermediate shaft in the model articular joint appears slave supporting seg- cop that meets the needs of a cyclical nature gait, as the implementation of the function of the interruption mechanism Strict movement. According to the author, such mechanisms we can be performed in a spatial form for implementation of a complex movement. Among the spatial mechanisms of intermittent movements endowed with an elastic link and characterize compact, highly efficient and highly accurate divided class of combined planetary-wave mechanisms developed and studied at the department "Theory of machines and mechanisms" MSTU. N.E. Bauman [25,28].

With the arrangement of joints has a similarity to the butt wave transmission [33]: they are united by an end elastic goy link, playing the role of cartilage and menisci, closed dense fibrous ring, the presence of a wave generator, as an analogue of the curvature of the articular surfaces and mobility of rotation centers reflecting movement both articular ends of the bones during the execution of the step. The role of gear assembly and mechanical bearings rolling takes on a two-phase pseudo-plastic fixed fluid. In the process of free smooth flow during joint opening, it reduces friction between surfaces and when loading a limb provides engagement in an extended contact spot, turning into an elastic state. Gradual, dependent from shear force a change in the phase state of the articular fluid from low viscosity to elastic provides a wide the range of conditions for the transformation of the moment is essentially the continuous change in gear ratio. Thus, based on available information, describing a multiscale device, dynamics and kinematics of a living joint, it is possible to joint identification of the joint model in a complex self-oscillating system with a nonlinear dissipation realized in the form of spatial mechanism

with the highest pair in the class of inertial mechanisms continuously variable pulsed gears with elastic gim link. This one, somewhat more complicated than a traditional ball.

The synergy of the synovial joint as It has the property of describing the processes of dynamic ki, kinematics and motion control in a single conceptual apparatus 4 and allows you to form the basis of a common understanding of biological tribosopri- life as a purposeful evolutionary adaptation. Consideration of the joint as a local self-oscillating a system included in the hierarchy of devices of living systems, endowed with discrete scale invariance, opens up a number of possibilities in cognition as a pheno exchange of locomotion of living mechanical systems in private case and the device of living matter, distinguishing- with a high degree of adaptation in general, evolving on understanding [23].

Findings and Conclusion

A large number of studies, a variety of would study kinematics using modern hardware and software systems have not yet led to the emergence of a generally accepted model of the synovial joint and, therefore, the task of identifying unique param- personification as a subject of many years of search, remains unsolved. Study of movement in the knee joint taking into account phenomena of new methods of radiation diagnostics and visualization, such as film-MRI, film-CT, computer optimization- Critical and inertial goniometry, making a big circle, goes back to the source - the formulation of the type hypothesis movements in the knee joint, essentially structural identification of the model of the synovial joint. Representation of a joint in a flat model the action of absolutely solid bodies is substantially roughened research results because there are internal logical (including metrological) contradictions in the interpretation of the data. To a much greater extent the joint model corresponds to the spatial model mechanism with a higher pair, taking into account the complex the dynamics of inertial interaction under conditions of non- linear friction and anisotropy of the elastic properties of the supporting segments. The process is objectively recorded in the joint mechanical energy transfer due to reversible the course of the phase state of joint fluid from viscous into elastic. Therefore, the joint must be considered Like a frictional moment transmission mechanism, divided by means of active friction control.

1. Examination of the articular joint presents-in the form of integration of two oscillatory systems within one model: friction self-oscillating system and systems of two inverted pendulums as related parametrically excited oscillators with non- dissipation.
2. There are mechanisms known from engineering studies and techniques corresponding to the anatomical and biomechanical device and purpose of the living joint. Famous four Dynamic and kinematic connetivity are different wave processes - the subject of study of fundamental scientific direction lion called nonlinear wave mechanics. dynamic and kinematic characteristics of these mechanisms will be used to implement parametric identification of the articular joint model nenia.
3. The information received should be taken into account when the work of fundamentally new biologically invariant joint arthroplasty systems.

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