New Trends and Problems in Material Processing Machine Design Theory

Wang Ailun Duan Jian Huang Minghui Zhong Jue

Abstract: Based on reviewing the historical background, prospecting for the development trend, analyzing the complicacy and mechanism and summing up some achievements and experiences in scientific research, several new problems and the possible direction of development in material processing technology and machine are proposed, such as, producing new concept materials possessing some specific and extraordinary properties by means of integrating and coalescing conelative frontier science and technology; and thereafter a brief discussion is given.

Keywords: interface; extraordinary physical field; procession machine; function material

1 The Time Background of Material Processing Machine

In the long span of history of human progress, many tools, machines and methods were created and a variety of materials with different properties were processed. Materials and its processing have become one of pillar and driving force of mankind progress. In pace with multi - polar competition in current world and people's striving perseveringly for happier life, material function goes beyond unceasingly men's knowledge and imagination, for example, cryptic function material ,semiconductor material ,energy material, vibration - absorptive material, super - strength aluminum alloy accounting for 70 percent of application of aeronautics and space ,metal foil of 4～5 μ m ,deep drawing plate with anisotropy below 1 percent, electronic aluminum foil with micro - orientation up to 95 percent, heat resisting aluminum alloy with super strong specific strength used in aeronautics, space and deep sea, etc. [1 ,2] Thus several important development trends with distinct time features in material processing domain are shaped up as follows:

(1) Creating material processing machine with extraordinary physical field for processing material with special texture structures and functions. For example, applications of thermal energy and mechanical energy are breaking through unceasingly technology limit, and some non - tradition energy, such as microwave, chemical energy, bioenergy, etc, are introduced into material processing procedure one after another, so that some material processing machines with extraordinary energy circumstance are produced.

(2) Breaking through traditional physical limits and integrating melting,

solidifying, plastic deformation and heat treatment to obtain special function of material and cut down expenses[3]. For example, near - net shaping material processing technology, such as fast rolling, spraying deposition, over - plastic molding, injection molding , high energy beam, etc, is applied.

(3) Material processing process is forged ahead in the direction of high speed, heavy - duty and high accuracy online control, for instance, the rolling speed goes up to 130 m·s $^{-1}$, the deformation pressure rises up to 300 MPa, accuracy of dimension up to 0.1μm, accuracy of shape up to 0. 1 I, strength accuracy comes up to 0.1 MPa. For these reasons, it is necessary for material processing machine design theory to integrate and coalesce ingeniously correlative frontier science and technology to create and produce some new concept material processing machine with following functions.

2 Due Functions of New Concept Material Processing Machine

(1) To have the ability to produce and bear extraordinary physical field and transmit extraordinary energy flow with the aim of providing extraordinary physical circumstances necessary for new concept material processing. For example ,high gradient temperature field with the speed of cool - down of work interface which exceeds 104 ～ 106 K·s $^{-1}$, line wave and pulse complex exerted in solidifying - deforming area, super - strength contact stress field of material forming interface, turbulent flow field of molten metal with very big flakiness ratio, low frequency magnetic field with random frequency, microwave field for powder metal heating, ultrasonic field for large volume solidifying, etc. [4], are applied.

(2) To have the ability to work in critical state so that high stability and ideal performance of processing machine is ensured under the circumstance of reinforced technological condition and multi - field coupling operation. For example, chatter suppressing capability of fast ultra - thin rolling under the condition of boundary lubricating state[5], the capability of self - excited vibration suppressing under the condition of special friction state, synergism stability and disturbance stability of flexible connecting parallel shaft with multi - driving system, etc. [4], are ensured.

(3) To have the ability to accurately control the material processing in order to obtain low loss, high efficiency and high quality of material processing. For example, super - high accuracy on - line monitor of products form, on – line monitor and on - line adjustment of products texture and properties ,precision coordination control of multi - procedure, on - line monitor of micro - orientation of metal plastic deformation, etc. [4], are ensured. Some products accuracy index may be enumerated as follows: dimensional accuracy coming to 0.1μm, microstructure

uniformity to crystal lattice, strength error to 0.1 MPa, etc. [4] In short, only by new concept material processing machine with extraordinary function being designed and made, can special function material be processed.

3 Science Problems and Study Contents of Metal Material Processing Machine

Under the Circumstance of Extraordinary Physical Field. In view of these facts and background mentioned above, several new research topics can be advanced as follows.

3. 1 Coupling Heat Transfer Mechanism of Multi - Phase Interface Temperature - Stress Field

A brand - new microstructure can be obtained through continuously large deformation and fast solidifying when melting metal is in critical state of liquid solid. At this very moment, high density heat flow and dynamic heat resistance are present in material processing circumstance[6 ,7]. A basic theory problem of designing this kind of machine is to study mechanism of heat transmittance and energy conversion, and to establish mathematical model.

3. 2 Friction Constraint Mechanism of Plastic Flow Interface of Material Processing Machine

The coupling between operation mechanism and workpiece is very complicated because plastic flow is present in processing interface. The interface state , determined by velocity, load thermodynamic process, elasticity of operation mechanism, plasticity of workpiece, dynamic behaviour of interface sticking - sliding and partial hydrodynamic lubrication, etc, affect and form friction constraints mechanism peculiar to material processing machine, because these constraints present strong non - linearity; and under certain circumstances, the constraints may be destroyed or mismatched instantaneously and thus dynamic instability is resulted in. Thus following problems can be put forward: Mechanism of“spectre chatter”arose from sticking - sliding friction and partial hydrodynamic lubrication in rolling interface, instability condition and mechanism of constraint between smooth surface and rotating body under the circumstance of high speed, heavy - duty and boundary lubrication, Lubrication film absorption mechanism and physical chemistry behaviour of interface of unceasingly regenerative surface, the relationship between rheological characteristic and machine operation parameters.

3. 3 Multi - Body Non - Linear Contact Mechanism Under the Condition of Extra - High Pressure Field

To build the super strength pressure field on large area is one of basic function of material processing machine, and it is also necessary to form by once large - size structure element (such as spacecraft , intercontinental vehicles ,car and large - scale aeroplane etc). The ability to build super strong pressure field is one of important feature and the base of independent national defense. Under the circumstance of super strength pressure field, multi - body strong nonhertz contact and non - linear friction will be produced, thus local permanent deformation and degrading of element accuracy may be led. New theory foundation of design of machine with super strength pressure field will be furnished through study of multi - body strong non - hertz contact mechanism , multi - body non - linear friction mechanism (such as providing force - displacement mixed solving process of three - dimension multi - body).

3. 4 Load Distribution Law in Multi - Sliding Pair With Structure Bias Load

With regard to statically indeterminate structure, load distribution of constraint point is determined by deformation compatibility condition. However, concerning some plane large - size statically indeterminate structure with sliding degree of freedom in third dimension, load distribution can not be determined by deformation compatibility condition. Thus new theory basis will be provided by analyzing of contact behaviour and mechanism of sliding pair (such as creep, force of friction, integral deformation compatibility condition, etc).

3. 5 Coupling Mechanism and Stability of Multi - Physical Fields in Material Processing Systems

In the wake of system function becoming more and more diversified, conventional technology limits in material processing machine is being broke through unceasingly, system structure also becomes increasingly complicated, and system performance becomes increasingly multi - causal . For example, any instantaneous state of roller in fast rolling mills is affected by elastic deformation ,plastic flow ,heat transfer process , hydro - dynamic lubrication process ,interface physical chemistry molecular state and so on[5]. In addition, electromechanical coupling in processing system have already gone beyond conventional concept ,for instance ,some singular point phenomenon (such as micro - variable can be transformed into macro - variable), are present, thus roller operation instability may be led by perturbation[8]. Therefore, this subject will study

the interaction mechanism of multi - physical field and the influence on processing system stability and processing material quality started with analysis of micro - state of executive body.

3. 6 Multi - Technology Integration and Coalescence of Accurate Control

The material processing machine, which operate under the circumstance of extraordinary physical field, is a complicated large - scale system, and some parameters of the system vary on feasible field boundary; thereby, to keep under accurate control and adjustment of multi field circumstance, multi - dimension coordination, multi - energy conversion, multi - level information transfer, interface multi - process coupling, etc. is of much significance. Since a variety of multi - interaction exists in control model, it is necessary to establish integration framework of coordination work according to decoupling of control model, so as to accurate control based on the multi - technology integration and coalescence is realized.

3. 7 Quasi - Reality Design and Concurrent Design Based on Knowledge Innovation Systems

Digitalization and visualization of material processing technology will promote immediately the quality of design, operation and control. Therefore optimization of material processing technology and material processing machine by means of realization of virtual simulation of processing procedure through quasi - reality design and concurrent design is one of our pressing study subjects.

3. 8 Mechanical Behavior of Special Function Materials in the Extraordinary Physical Field

Many key elements and parts in material processing machine are often under the circumstance of super strong force field, temperature field, electronic magnetic field and flow field, and must have the functions of constructing special physical interface. However, it is difficult for common single - substance material such as metal, ceramic polymer, etc. to have both high index of single property and excellent overall quality. Therefore we need to use certain material with new functions for key position[9], for instance, multi - dimension function gradient material with ultrahigh physical property, multi - dimension function gradient material with intelligence. For these reasons, it is necessary to study basic law and mechanism of these kind of function material mentioned above, for instance, stress (strain) distribution function ,failure mechanism and design criteria of material under the circumstance of extraordinary physical field, static (dynamic) stiffness and damping, digitalization

design and visualization design of processing system made of gradient function material, etc, so that the general mechanics law of element which is under the circumstance of extraordinary physical field and made of anisotropy multi - dimension gradient function material is obtained.

Nowadays, material processing science and technology is forging rapidly ahead. A forward - looking study aiming at key technology problem of material processing machine will provide theory and technology reserve for manufacturing science and industry of 21st century.