Chin. J. Mech. Eng. (2017) 30:231–240
DOI 10.1007/s10033-017-0080-x

REVIEW

Present Situation of the Anti-Fatigue Processing of High-Strength Steel Internal Thread Based on Cold Extrusion Technology: A Review

Hong MIAO[1,2] · Cheng JIANG[1] · Sixing LIU[1] · Shanwen ZHANG[1] · Yanjun ZHANG[1]

Received: 21 September 2016 / Revised: 14 November 2016 / Accepted: 25 November 2016 / Published online: 21 March 2017

Abstract The adoption of cold-extrusion forming for internal thread net forming becomes an important component of anti-fatigue processing with the development of internal thread processing towards high performance, low cost and low energy consumption. It has vast application foreground in the field of aviation, spaceflight, high speed train and etc. The internal thread processing and anti-fatigue manufacture technology are summarized. In terms of the perspective of processing quality and fatigue serving life, the advantages and disadvantages of the processing methods from are compared. The internal thread cold-extrusion processing technology is investigated for the purpose of improving the anti-fatigue serving life of internal thread. The superiorities of the plastic deformation law and surface integrity of the metal layer in the course of cold extrusion for improving its stability and economy are summed up. The proposed research forecasts the development tendency of the internal thread anti-fatigue manufacturing technology.

Supported by National Natural Science Foundation of China (Grant No. 51672241), International Cooperation Foundation of Ministry of Agriculture of China (Grant No. 20162003), Collaborative Innovation Program of Industry University Research of Jiangsu Province China (Grant No. BE2015113), Young and Middle-aged Academic Leaders of Universities "Qinglan Project" of Jiangsu Province 2016, and Foundation of Key Laboratory of Modern Agricultural Equipment Ministry of Agriculture, China (Grant No. 201604003).

✉ Hong MIAO
mh0514@163.com

1 College of Mechanical Engineering, Yangzhou University, Yangzhou 225009, China

2 Key Laboratory of Modern Agricultural Equipment, Nanjing Research Institute for Agricultural Mechanization Ministry of Agriculture, Nanjing 210014, China

Keywords High-strength steel · Internal thread · Cold extrusion · Anti-fatigue · Surface integrity

1 Introduction

With the rapid development of economy, science and technology, the output and inventory of airplane, high speed train, automobile and etc. are increasing continuously. Accordingly, the energy consumption is also increasing progressively year by year. Currently, it appears the phenomenon of energy shortage [1]. To achieve the purpose of saving limited resources and preventing the increasingly environmental degradation, the development of light-weight technologies for airplane, high speed train, automobile and etc. is now the important way to realize the energy conservation and emission reduction [2–10]. As the most common one among the connection mode, the threaded connection is frequently used. And it is usually used for connecting vitally important fasteners and structural parts. Its performance has a direct bearing on the serving life of airplane, high speed train, automobile and etc. Therefore, this raises new challenge to designers, which requires the designed internal thread past to meet the requirement of reliable performance, long serving life, simple structure and relatively light weight at one time. At present, the processing of thread parts, especially the processing of thread in high accuracy, complex shape and difficult-to-process material, the problems such has low accuracy, low production efficiency, long cycle, high cost, high labor intensity and etc. are universal. This seriously impact its performance and serving life [11–13].

As we know, among the material forming technologies, cold-extrusion processing forming is one of the technologies having the best performance on net forming. The parts from cold-extrusion processing forming have stable quality, high accuracy, and are suitable for volume-production. With the development of internal thread processing towards high performance, low cost and low energy consumption, the adoption of cold-extrusion forming technology becomes the development tendency of the internal thread's anti-fatigue manufacture for airplane, high speed train and automobile. For example, the internal threads of landing gear cylinder M135×1.5 has adopted the cold-extrusion forming technology [14], as shown in Fig. 1. Internal thread cold-extrusion technology is a kind of new internal thread processing technology. It is a technical process at room temperature which forms the internal thread by using thread forming tap to make the metal generate plastic flow on the bottom hole of prefabricated workpiece through the effect of the tap's edge teeth. For the manufactured internal thread products by internal thread cold-extrusion forming, its surface quality, dimensional accuracy, material utilization and mechanical performance are all superior to traditional processing mode. It is the important part of anti-fatigue processing technology.

Although internal thread cold-extrusion technology can generate cold hardening on the surface of thread, and improve internal thread's fatigue life, there still exist some deficiencies during the promotion and application [14]:

(1) High requirement on thread forming tap. During the cold extrusion of internal thread, the thread forming tap will dramatically increase the resistance to deformation by bearing the three-dimensional compressive stress. The stress on thread forming tap is far larger than other internal thread processing mode. It requires that the thread forming tap shall not only have high strength, but also have enough impact toughness and abrasive resistance. Therefore, the serving life of thread forming tap is usually short.

(2) The manufacturing technique of thread forming tap is complex and in high cost. It is usually applicable for being used to volume-produce internal thread parts only.

(3) It is inappropriate to process chute thread hole, incomplete thread hole and thin-wall thread hole.

(4) It is not applicable to process brittle materials and high strength materials.

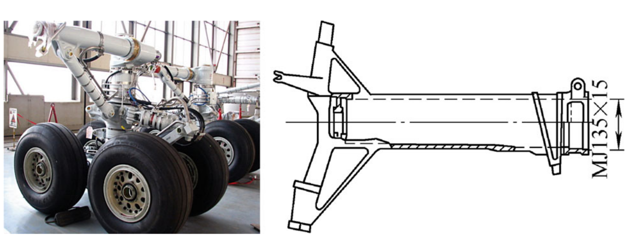

Fig. 1 Outer dimensions of the landing gear [14]

(5) The cold-extrusion internal thread is poor in plasticity and impact toughness. Moreover, it has large residual stress on the surface layer, which is easy to cause deformation on the internal thread.

(6) Internal thread cold-extrusion processing has high requirements for the bottom hole of workpiece, except for the relatively high dimensional accuracy; it also requires surface lubrication on the workpiece before the cold-extrusion.

Due to above situations, to further promote the internal thread cold-extrusion technology, it must extend the serving life of thread forming tap from the aspect of design, material and manufacturing technique of thread forming tap, and to improve the internal thread cold-extrusion technology, so as to continuously extend its application scope, finally to enable it to be an important method in modern internal thread machinery manufacturing.

Therefore, this article mainly aims at summarizing current technologies of internal thread processing and anti-fatigue manufacturing. It also introduces the processing method and its development history in different categories, and makes comparison and analysis. It introduces the internal thread cold-extrusion processing technology for the purpose of improving the anti-fatigue serving life of internal thread. It analyzes and sums up the performance advantages and application prospect of current cold-extrusion processing technology. By analyzing the hot points, difficult points and existent main problems on study of internal thread cold-extrusion technology, this article also forecasts development tendency of internal thread anti-fatigue manufacturing technology.

2 Current Situation of Internal Thread Processing & Anti-Fatigue Manufacturing Technology

2.1 Internal Thread Processing Technology

There are many manufacturing methods for internal thread, as shown in Fig. 2. The earliest one could be traced back to the end of the 2nd century AD. Over two hundred years

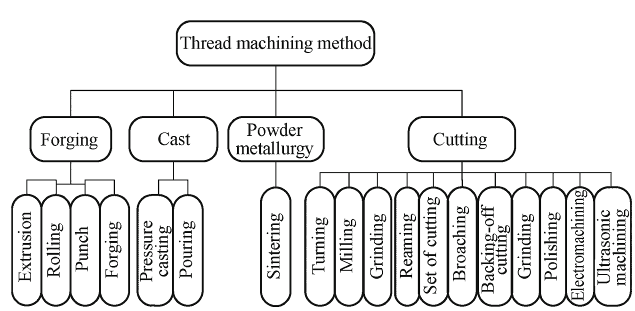

Fig. 2 Processing methods of internal threads

ago, people had already mastered the technology of processing internal thread by using cutting tools. Such technology belonged to the category of chipping and tapping technology. In current machinery manufacturing industry, the machinery equipment with internal thread cutting processing include: drilling machine, lathe, milling machine, special tapping equipment and etc, the cutting tools includes: lathe tool, milling cutter, screw tap and etc [15–22].

Currently, precision and ultra-precision machining, high-efficiency machining have become one of the indispensable key technologies for further development of aero, space, automobile, ship, military-industrial complex, electronics industry, medical and other industry. Certainly, this has become the main direction of thread processing research. With the continuous development of aero and space technologies in China, the requirements on precision manufacturing are higher and higher. There arise a lot of new technologies such as internal thread milling technology, vibration tapping technology, electrospark wire-electrode cutting technology, high-speed tapping technology, extrusion processing technology and etc. These technologies greatly improve the manufacturing accuracy, serving life and production efficiency of internal thread.

At present, western developed countries commonly adopt thread milling technology to process thread. It realizes the thread processing by the thread interpolation function of numerically-controlled machine tool. Although the thread milling technology has been rapidly developed in recent years, it is only fit for the processing of large diameter external thread. Minor diameter thread, especially the internal thread processing, rarely adopts the thread milling technology [23–26].

High-speed tapping may be divided into two types: floating tapping and rigid tapping which doesn't require any compensating action. In the course of processing, floating tapping is not able to accurately control the axial displacement of screw tap, thus cannot ensure the processing accuracy of thread pitch. Therefore, generally it can only be used to process thread in ordinary accuracy. High-speed rigid tapping, is a method of processing thread by utilizing the screw tap's forward high-speed spiral movement and backward rollback movement. Although such method can improve thread's processing accuracy, it has the shortcoming of large inertia on machine tool spindle, long processing time, low production efficiency. Therefore, high-speed rigid tapping is not fit for the volume-processing of thread parts, but only fit for small-amount processing of thread parts [27–31].

The electro-sparking thread combines the electro-processing principle and related principle of mechanical motion. It mainly contains two processing methods. The first one: the tool electrode copies its thread onto workpiece via electro-discharge machining under the control of mechanical motion parameter. The second one: use simple electrode and enter thread parameter according to machining principle, then directly process the required thread. The electro-sparking thread solves the internal and external thread technological problems on cemented carbide workpiece, hardens workpiece or on big parts made in special difficult-to-process materials which is difficult for machining by mechanical methods [32, 33].

Japanese Professor Kumabe Junichiro firstly presented vibration tapping technology in 1960s. After that, USA, Russia and etc. also studied this technology in succession. China did not start studying such technology until in late 1960s. Vibration tapping belongs to a branch of vibration cutting technology. It is a machining process on the basis of traditional tapping technology, through adding a controllable periodic vibration on the lift angle direction of the screw tap's movement, and turning the consecutive cutting process into discontinuous and repeated cutting process. Thus, it effectively reduces the torque and temperature in the course of processing, and improves the thread's processing quality and screw tap's serving life. Vibration tapping technology has certain advantages in the aspect of processing minor diameter internal thread, especially the minor diameter internal thread in difficult-to-process material [34–36]. Although it can significantly improve the serving life of screw tap and the processing quality of thread, researchers have not solved the technological problem of processing large diameter internal thread in difficult-to-process material by vibration tapping. To some extent, this limits its application scope.

Extrusion tapping technology is a method which utilizes the edge teeth of thread forming tap to make the metal in workpiece's deformation zone generate plastic flow, and finally forms the thread [37]. Due to the repeated extrusion for many times, it forms strengthened layer on the thread surface, which refines the crystal grain on material microstructure, increases the dislocation density, and enlarges the lattice distortion and fibration degree. It forms relatively high macroscopic residual stress in the strengthened layer, so as to reduce the thread's surface roughness. The formed strengthened layer enhances the material's yield strength and fatigue strength, and the reduction of surface roughness can decrease the surface defect, namely decrease stress concentration, which is beneficial to enhance the material's fatigue strength. The formed residual compressive stress on workpiece surface can effectively decrease the crack propagation rate and the sensibility of part to gap [38]. With the development of aviation and aerospace flight technologies in China, the requirements on screw thread fasteners is higher and higher. Internal thread cold-extrusion processing technology is a new technology for increasing the anti-fatigue performance of the thread in airplane's landing gear. It has vitally important effect on realizing same serving life of airplane's landing gear as the airframe.

2.2 Anti-Fatigue Manufacturing Technology

Among current production practices, there are various methods of anti-fatigue manufacturing. They are mainly divided from four aspects: machinery, chemistry, physics and high energy beam, as shown in Fig. 3 [14].

The anti-fatigue manufacturing methods in mechanical aspect include shot peening, rolling, cold-extrusion and etc. They mainly utilize the plastic deformation to generate cold hardening on workpiece's metal surface. This can increase the rigidity and strength of the metal surface. The formed residual compressive stress field on the surface, can relief the influence of stress concentration, decrease the fatigue notch sensitivity, extend the crack initiation period, slower or restrain the propagation of crack, and contribute to increase workpiece's fatigue life. The anti-fatigue manufacturing methods in chemical aspect mainly utilize chemical heat treatment to permeate the atoms of one or more kinds of chemical elements from the surface of workpiece, such as carbon, nitrogen, boron and etc. Thus, it will change the chemical component, microstructure and property of the workpiece's surface, and the workpiece will have high anti-fatigue performance. The anti-fatigue manufacturing methods in physical aspect, are to increase the anti-fatigue strength of workpiece through changing the group phases on the surface based on not changing the metal chemical component of the workpiece's surface. It mainly contains the surface hardening processing technology in heat treatment. High energy beam processing is a new approach in the field of anti-fatigue manufacturing, which exerts energy in extremely high-density on the local surface of workpiece, and make it occur physical and chemical changes. Thus, it can realize the purpose of anti-fatigue and increasing serving life. It mainly includes laser treatment, plasma bombardment and etc.

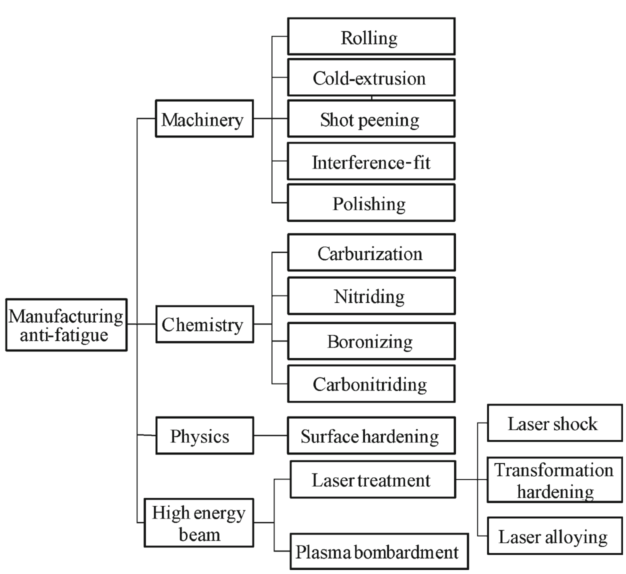

Fig. 3 Classification of anti-fatigue manufacturing technologies

According to above classification of anti-fatigue manufacturing technologies, the summarized current research situation of anti-fatigue manufacturing technologies is shown in Table 1.

3 Advantages of Processing Internal Thread by Cold-Extrusion and its Application & Performance

3.1 Advantages of Internal Thread Cold-Extrusion Processing

The internal thread cold-extrusion technology is a new internal thread processing technology. It is a technical process at room temperature which forms the internal thread by using thread forming tap to make the metal generate plastic flow on the bottom hole of prefabricated workpiece through the effect of the tap's edge teeth. For the manufactured internal thread products by internal thread cold-extrusion forming, its surface quality, dimensional accuracy, material utilization and mechanical performance are all superior to traditional processing mode. It is the important part of anti-fatigue processing technology. Its advantages mainly include [14]:

(1) Save raw materials. Internal thread cold-extrusion processing metal's utilizes plastic deformation to manufacture parts in required shape. It is a non-cutting processing technology. It can significantly increase the material utilization ratio.
(2) Increase the processing accuracy of internal thread. The form and position error of cold-extruded internal thread is very small. For general materials, it is easy to reach the accuracy of 4H5H.
(3) Workpieces can obtain ideal surface roughness. In the course of extrusion, the edge teeth on the pyramis of the thread forming tap generates extruding effect to the thread surface. The surface roughness of cold-extruded internal thread can reach Ra0.4～0.8. Therefore, the internal threads processed by cold-extrusion are rarely re-processed, and only need some accurate grinding at positions having especially high requirement.

Table 1 Current Research Situation of Anti-Fatigue Manufacturing Technologies

Type	In the world	In China
Theoretical research	Systematic, all-around, in-depth research	Haven't involved the relationship between part manufacturing technology and its fatigue performance
Manufacturing technology	Plastic forming processing, deep "carburization" and "nitridation" high energy composite surface modification new technology	Imitative, single and simple heat-treatment strengthening technology
Equipment and technology	Innovative high-performance equipment and special combined processing new technology	Traditional turning, milling and grinding machining means, no advanced combined machining equipment technology is seen
Quality evaluation	Establish anti-fatigue manufacturing quality detection system and healthy monitoring platform, develop new lossless on-line detection technology and health monitoring, research and develop relevant equipment	No mature quality evaluation system is seen

(4) Enhance the mechanical strength of internal thread. After the cold-extrusion forming of the internal thread, the metal in surface layer appears cold hardening, the surface structure fiber is refined, forms reasonable streamline distribution along the thread form, and exists residual stress field in certain depth on the surface layer, makes the tensile strength and anti-fatigue performance of cold-extruded internal thread is far higher than the tensile strength and anti-fatigue performance of cold-extruded internal thread processed by other methods. Therefore, some internal thread parts originally required heat-treatment strengthening, may omit the heat-treatment technology once adopting the cold-extrusion technology; some internal thread parts originally required to be made in rolled steel with relatively high strength, may be replaced by rolled steel with relatively low strength once adopting the cold-extrusion technology.

(5) Increase the processing efficiency of internal thread. It will significantly increase the production efficiency if using cold-extrusion technology to replace other processing technology for manufacturing internal thread parts.

(6) Fit for processing deep-hole and blind-hole thread. Since internal thread cold-extrusion processing doesn't need to clean up cuttings, so it reduces or avoid the possibility of tooth breakage or break off on screw tap caused by chip removal difficulty.

(7) Lower the production cost. Since internal thread cold-extrusion processing technology has the advantage of saving raw material, increasing production efficiency, reducing the processing volume of parts, being possible to use material in lower level to replace quality material, so it can significantly reduce the cost of internal thread parts.

3.2 Application of Cold-Extruded Internal Thread and its Performance

The internal thread processed by chipless cold-extrusion has surpassed the internal thread processed by traditional processing methods having chips on the physical performance of tensile strength, fatigue performance, surface hardness and etc, as shown in Table 2 [14]. With the optimization design of the screw tap's geometrical shape and continuous growth improvement of, such chipless processing technology is able to apply to increasingly wider workpiece materials.

In 1970s, thread cold-extrusion forming processing technology was applied in process workshop. In modern equipment and instruments, about more than 70% of parts have internal thread [14]. At present, in those countries with internationally advanced industry, 41% of the products' internal threads are processed by thread forming tap, but China still have great gap on the promotion and application in this aspect.

In the optical industry of China, the cold-extrusion processing of medium and small screw hole on non-ferrous metals aluminum alloy and copper alloy has achieved satisfactory results; the cold-extrusion processing of screw hole with medium diameter and high accuracy on high-plasticity and high-toughness low-carbon steel, high-quality carbon structural steel, alloy steel and etc. has achieved gratifying successes [14]. With the development and popularization of the advanced technologies such as big airplane, high speed train and etc. in China, the fatigue failure problem on key parts becomes increasingly prominent. For the internal thread parts as key parts and with more usage quantity, China mainly relies on import to. Other countries are still in block stage for such kind of technologies. Therefore, to further improve China's overall technological level on these advanced technologies; it is necessary to

Table 2 Comparison on physical performance of processing with chip and cold-extrusion internal thread chipless processing

Sample material (imposed stress)	Thread machining method	Fatigue life N / 10^3	Hardness HV	Strengthening degree H / %
300 M (500 MPa)	Chipless	5.6, 2.8, 5.5, 4.7, 3.9	530	2–4
	Chip	94.3, 93.1, 47.7, 89.1, 68.5	780	52
30CrMnSiA (470 MPa)	Chipless	8.5, 8.1, 6.8, 12.5, 10.5	–	–
	Chip	96.2, 26.1, 28.5, 59.1, 28.9	460	45
45Steel (320 MPa)	Chipless	24.3, 20.1, 18.5, 23.8	290	10
	Chip	66.3, 62.7, 51.6, 70.8	380	40

conduct in-depth research on internal thread cold-extrusion technology.

4 Research Progress of Internal Thread Cold-Extrusion Processing Technology

4.1 Internal Thread Cold-Extrusion Processing Technology

As early as 1983, other countries started the research of external thread rolling technique, which has been widely applied since 1940. This is mainly because the blank materials were inapplicable for rolling. ASM International introduced the thread cold-rolling, and made analysis on the thread materials and several frequently-used thread rolling method [39]. Comparing with external thread rolling technique, the research and application of internal cold-extrusion technology has a comparatively later starting; its development history is shown in Table 3.

The earliest application of internal thread cold-extrusion technology could be traced back to 1940s and 1950s. Due to lack of in-depth research and practical application, it caused large extrusion torque when processing internal thread, and generated lots of heat in the course of extrusion. Except processing copper alloy, the serving life of thread forming tap was all short. After the seventies, UK BAJ Vickers Ltd once carried on come trials on the internal thread cold-extrusion forming of minor diameter high strength steel(-chrome-molybdenum steel). Afterwards, with the development of high-performance thread forming tap, the application scope of the internal thread cold-extrusion processing technology was extended [40], and was no longer limited to the internal thread processing of alloy steel with tensile strength less than 600 MPa and elongation over 12% and non-ferrous metals. For most alloy steel, even the material of heat-treatment steel with 900 MPa of tensile strength, aluminum alloy with low elongation and etc., it is expected to obtain high accuracy internal thread by adopting the cold-extrusion processing method.

In 1960s, Professor Kumabe Junichiro from Japan Utsunomiya University conducted in-depth systematic research on the vibration tapping technology. It raised widespread concerns from researchers soon because of its good processing effect. After that, USA, Russia and other countries started researching this technology in succession. China did not start the research on such technology until late sixties. XU, et al [41], from NUAA(Nanjing University of Aeronautics and Astronautics) raised the opinion of combining vibration

Table 3 Development of Internal Thread Cold-Extrusion Technology

Time	Representative	Research achievement
Before 1960	Europe, USA	Long extrusion torque, short serving life
1960	Japan, USA, the Soviet Union	Conducted in-depth theoretical research, tried vibration tapping technology
1970	UK	Tried minor diameter high strength steel internal thread cold-extrusion technology
1980	the Soviet Union, USA, China	Further conducted theoretical research, tried different internal thread cold-extrusion technology, the Soviet Union was in the leading position on the theoretical research and technology of large diameter internal thread
After 1990	China, Russia	Conduct in-depth theoretical and technological research in the aspect of internal thread cold-extrusion on high strength steel and non-ferrous alloy

tapping technology with internal cold-extrusion, which may solve the extrusion forming problem of large diameter internal thread in high strength steel. The former Soviet Union kept in leading position on the basic theoretical research and technological development of cold-extruding large diameter internal thread, and its industrialization also played a leading role in the world.

XU, et al [41, 42], raised the theory, calculation and design issue on the thread forming tap, its application method and reasonable application scope, further perfect the design calculation and manufacture of thread forming tap's structure. LIU, et al [43], deduced the theoretical formula for calculating the dimension of internal thread bottom hole based on the cold-extrusion forming mechanism, researched the influence of bottom hole dimension to extrusion torque and thread-height ratio, and modified the theoretical formula.

GUO, et al [42–44], completed the internal thread cold-extrusion forming by utilizing the plastic deformation of non-ferrous material, and introduced its advantages. Liu, et al [43], conducted the research on extrusion processing technology for internal thread of pure aluminum workpiece, and optimized the technological parameters. XU, et al [45, 46], applied the cutting-extrusion composite technology to the processing of titanium alloy internal thread, which solved the anti-fatigue manufacturing challenge of internal thread in titanium alloy structural components. SUN, et al [47], raised the method of processing minor internal thread in stainless steel workpiece by adopting cutting-extrusion composite technology, and optimized the technological parameters and the machining allowance allocation of cutting tap and thread forming tap. XU, et al [41], applied the internal thread cold-extrusion technology to the high strength steel, and developed the torque and temperature measurement system, but they did not conducted specific research on the influence of technological parameters to the quality of cold-extruded internal thread and on-line measurement signal, and on the anti-fatigue mechanism of cold-extruded internal thread.

SUN, et al [47] researched the application of 8031 singlechip of MSC-51 series in the cold-extrusion forming process monitoring of large diameter internal thread in 300 M steel, provided hardware block diagram and software procedure, and discussed the anti-interference measures in monitoring system.

At present, theoretical researches on internal thread extrusion forming processing mainly focus on the design of thread forming tap and the calculation of workpiece bottom hole diameter. The experimental research are mainly cold-extrusion experiments for minor diameter internal thread on those materials such as some non-ferrous metals and their alloy, low-carbon steel and quenched and tempered steel with relatively low harness, alloy steel, stainless steel and alloy tool steel, etc [42–45]. The internal thread cold-extrusion processing of high strength steel was researched in this article. Since high strength steel has relatively high strength and relatively large plastic deformation resistance, traditional internal thread cold-extrusion processing technology is unable to satisfy the processing of such material. This is because, if processing thread hole in relatively high strength material with a requirement of high accuracy, to achieve the quality effect, it is a precondition to guarantee the processing accuracy and surface roughness of the thread bottom hole. The deep hole working is comparatively difficult, as the hole is deep, taper-rod is thin and long, the screw tap is easy to be pushed to a deviation, lubricating fluid is difficult to enter into the main extrusion area of the tap head, all which cause the cooling difficulty of thread forming tap, speed up the abrasion of tap head, decrease the durability of thread forming tap, and limit the increase of extrusion efficiency. In addition, traditional cold-extrusion processing is mainly applicable to process internal thread below M30 minor diameter, and the research of large diameter internal thread cold-extrusion forming is always a difficult point in internal thread cold-extrusion processing. With the increase of diameter, to ensure part's processing accuracy and serving life, it is necessary to adopt special cold thread forming tap. Normal cold-extrusion thread forming tap has a diameter below M30, which can only satisfy the requirement of low strength and easy-to-process material. Moreover, if adopting normal method for clamping, since high strength steel has relatively high strength and relatively large plastic deformation resistance, it will bear extremely large resistance in the course of extrusion processing, and require large clamp force effect. However, the extruded piece is the workpiece with relatively thin wall. Therefore, this will impact the dimensional accuracy and shape accuracy of the workpiece in the course of clamping the workpiece. During the cold extrusion, the workpiece is affected by extrusion force in axial direction and thermal deformation, its dimension is difficult to controlled in reasonable scope. Therefore, it will impact the workpiece's dimensional, shape, positional accuracy and surface roughness.

China is still in staring stage on the aspect of internal thread cold-extrusion processing, some Chinese units have been engaged in the research on such technology and its industrialization in succession. Units having comparatively more researches include: Nanjing University of Aeronautics and Astronautics(NUAA), Guangdong University of Technology, Chongqing University, Xinjiang University, Shanghai Tools Plant, Jiangsu Tiangong Tools Co. Ltd and etc. They have acquired certain research achievements, such as cold-extrusion forming technology for internal thread in ultrahigh-strength steel and test research on cold-extrusion for internal thread 300 M high-strength steel by NUAA, Central South University of Technology has conducted experimental research on cold-extrusion for thin-wall internal thread [42–44]. However, there is still no in-depth systematic research on processing technology of cold-extruding internal thread, which restricts industrialization development of cold-extruding internal thread.

4.2 Finite Element Numerical Simulation for Internal Thread Cold-Extrusion Process

In the field of internal thread's cold-extrusion forming metal plastic forming, the finite element simulation of metal plastic forming may be divided into flowing-type plastic finite element method and solid-type plastic finite element method. The former contains rigid-plastic finite element method and rigid-viscoplastic finite element method; and the latter contains large deformation elastic-plastic finite element method and small deformation elastic-plastic finite element method. In 1967, Marcal, King et al. adopted the method of combining elastic deformation and plastic deformation, firstly raised the elastic-plastic finite element, its plastic deformation adopted Prandtl-Royce equation and Mises yield riterion, and the plastic deformation adopted Hooke's law [48]. In mid 1970s, Osias and McMecking perfected the large deformation elastic-plastic finite element method, and successfully applied to engineering practice [49]. JIEN, et al [10], conducted the finite element analysis on the metal plastic forming process by rigid-plastic finite element method for the first time, which further perfected the large deformation elastic-plastic finite element method, and significantly facilitated the practical application of finite element analysis in metal plastic forming. The plastic forming process of metal is a very complex process, it has many influence factors, such as residual stress inside the metal in the course of forming, and the influence of lubrication method changes to plastic forming, Therefore, it is necessary to further perfect the finite element simulation technique for metal plastic forming.

Relevant finite element numerical simulation research on external thread rolling depression has already been conducted. For example, JOSEPH, et al [15, 50], simulated the thread cold rolling depression: simplified the thread rolling depression as plane strain problem, ignored the influence of elastic deformation and temperature effect, and conducted the simulation by taking blank piece as rigid plastic body, thus acquired the forming process of thread teeth shape and the metal flow direction. They conducted three-dimensional simulation for the thread rolling process, but since thread forming belongs to small deformation, the counting process is complex, and requires high-performance computing device, they did not obtain any substantive conclusion. GELLINGS, et al. raised a new method of rolling sleeper fixed screw bolt, and conducted simulation and experimental research of finite volume method and finite element method on such method, and verified its feasibility [51].

GE, et al [52, 53], conducted finite element numerical simulation research on cold-extrusion forming of hook shaft's internal thread by using software DEFORM, simulated and analyzed the law of internal thread cold-extrusion forming and the influence law of workpiece bottom hole's diameter and extrusion speed to torque. But they have not acquired the stress field and temperature field in the course of internal thread cold-extrusion, and the law of influence of each technological parameter (diameter of workpiece's bottom hole, extrusion speed, extrusion times, on them friction factor) on them [54–58]. The work of such part in this article is to conduct finite element simulation of cold-extruding internal thread by software DEFORM, and conduct effective simulating calculation for the process of internal thread cold-extrusion forming [59, 60].

5 Conclusions

(1) The analysis of research progress on internal thread cold-extrusion processing technology and the researches on such field are still in starting and exploratory stage.
(2) The theoretical research focuses the design of thread forming tap and the calculation of work piece's bottom diameter, which is short of mechanical model research during internal thread cold-extrusion forming process.
(3) The plastic deformation law and surface integrity of the metal layer in the course of cold extrusion are used to improve its stability and economy.
(4) Above mentioned difficult points and existent problems about research on internal thread cold-extrusion processing technology provide referential research orientation for relevant research on anti-fatigue manufacturing technology.
(5) The proposed research forecasts the development tendency of the internal thread anti-fatigue manufacturing technology.

Appendix

Appendix and supplement both mean material added at the end of a book. An appendix gives useful additional information, but even without it the rest of the book is complete: In the appendix are forty detailed charts. A supplement, bound in the book or published separately, is given for comparison, as an enhancement, to provide corrections, to present later information, and the like: A yearly supplement is issue.

References

1. KANG Yonglin. Lightweight vehicle, advanced high strength steel and energy-saving and emission reduction[J]. *Iron and Steel*, 2008, 6(43): 2–7.
2. QIAN Sijia. Reserch on the development strategy of China's large aircraft manufacturing industry[D]. *Shanghai: Shanghai Jiao Tong University*, 2008.
3. JI Qian. *Research on fatigue reliability analysis method of aircraft landing gear*[D]. Nanjing: Nanjing University of Aeronautics and Astronautics, 2007.
4. MIAO Hong, ZUO Dunwen, WANG Hongfeng, et al. Effect of impact load on threaded connection of an aircraft landing gear[J]. *Journal of Vibration and Shock*, 2010, 2(29): 208–211.
5. FRANCO L, LOURENCO N J, GRACA M, et al. Aircraft fracture of a nose landing gear in a military transport aircraft[J]. *Eng Fail Anal*, 2006, 13: 474–9.
6. WANG Renzhi, RU Jilai. Overall evaluation of the effect of residual stress induced by shot peening in the improvement of fatigue fracture resistance for metallic materials[J]. *Chinese Journal of Mechanical Engineering*, 2015, 28(2): 416-421.
7. FETULLAZADE E, AKYILDIZ H K, SARITAS S. Effects of the machining conditions on the strain hardening and the residual stresses at the roots of screw threads[J]. *Materials and Design*, 2009, 31: 2025–2031.
8. ARAUJO A C, MELLO G M, CARDOSO F G. Thread milling as a manufacturing process for API threaded connection: Geometrical and cutting force analysis[J]. *Journal of Manufacturing Processes*, 2015, 18: 75–83.
9. OSSA E A. Failure analysis of a civil aircraft landing gear[J]. *Engineering Failure Analysis*, 2006, 13: 1177–1183.
10. JIEN J C, YAN S. A study of the helical effect on the thread connection by three dimensional finite element analysis[J]. *Nuclear Engineering and Design*, 1999, 191: 109–116.
11. LIN Yueguo, CHENG Jialin, FENG Zhenyu, et al. Parameter modeling and optimization analysis for landing gear absorber[J]. *Journal of System Simulation*, 2008, 10(22): 2732–2735.
12. WANG Mingxin. *Analysis of fatigue characteristics of a certain type nose landing gear*[D]. Nanjing: University of Aeronautics & Astronautics, 2007.
13. ZHOU Dong, WU Huiyong. Performance analysis of loading device based on the lever principle for landing gear fatigue test[J]. *Aircraft Design*, 2008, 1(28): 20–22.
14. LIANG Yuxuan, LI Xiangfeng, ZUO Dunwen. Experimental research on internal thread formation by cold extrusion based on low frequency vibration[J]. *Acta Aeronautica et Astronautica Sinica*, 2013, 34(2): 442–450.
15. DOMBLESKY J P, FENG Feng. A parametric study of process parameters in external thread rolling[J]. *Journal of Materials Processing Technology*, 2002, 121(2–3): 341–349.
16. ANNA C A, JOSE L S, MARTIN BG. A model for thread milling cutting forces[J]. *International Journal of Machine Tools and Manufacture*, 2006, 46(15): 2057–2065.
17. CHIANG C J, FONG Z H, TSENG J T. Computerized simulation of thread form grinding process[J]. *Mechanism and Machine Theory*, 2009, 44(4): 685–696.
18. MIAO, H, ZUO D W, WANG M, et al. Numerical calculation and experimental research on residual stresses in precipitation-hardening layer of NAK80 steel for shot peening[J]. *Chinese Journal of Mechanical Engineering*, 2011, 24(3): 439–445.
19. ZHANG Junhong, YANG Shuo, LIN Jiewei. Fatigue crack growth rate of Ti-6Al-4V considering the effects of fracture toughness and crack closure[J]. *Chinese Journal of Mechanical Engineering*, 2015, 28(2): 1–7.
20. LIANG Yuxuan. Research on internal thread formed by cold extrusion based on low frequency vibration[J]. *Acta Aeronautica et Astronautica Sinica*, 2013, 34(2): 442–450.
21. WU Shuangjie. Deep hole thread processing method discussion[J]. *Coal Mine Machinery*, 2007, 28(9): 125–126.
22. ELDAR F, HAMZA K, AKYILDIZ, et al. Effects of the machining conditions on the strain hardening and the residual stresses at the roots of screw threads[J]. *Materials & Design*, 2010, 31(04): 2025–2031.
23. BRATAN S, NOVIKOV P, ROSHCHUPKIN S. Application of combined taps for increasing the shaping accuracy of the internal threads in aluminium alloys[J]. *Procedia Engineering*, 2016, 150: 802–808.
24. LIANG Yuxuan, LI Xiangfeng, ZUO Dunwen et al. Dynamic simulation for a vibration processing equipment of internal thread formed by cold extrusion based on low frequency vibration[J]. *Journal of Vibration and Shock*, 2012, 31(22): 143–146.
25. SULLIVAN A, ERDIM H, PERRY R N, et al. High accuracy NC milling simulation using composite adaptively sampled distance fields[J]. *Computer-Aided Design*,2012, 44 : 522–536.
26. FU Yucan, GE Ende, SU Honghua, et al. Cold expansion technology of connection holes in aircraft structures: A review and prospect[J]. *Chinese Journal of Aeronautics*, 2015, 28(4): 961–973.
27. GERIN B, PESSARD E, MORAL F, et al. Beneficial effect of prestrain due to cold extrusion on the multiaxial fatigue strength of a 27MnCr5 steel[J]. *International Journal of Fatigue*, 2016, 92: 345–359.
28. PENG Erbao, ZHANG Guotong. Image processing technology research of on-line thread processing[J]. *Energy Procedia*, 2012, 17: 1408–1415.
29. AHN J H, KANG D B, LEE M H et al. Investigation of cutting characteristics in side-milling a multi-thread worm shaft on automatic lathe[J]. *CIRP Annals-Manufacturing Technology*, 2006, 55(1): 63–66.
30. ZHANG Min, LI Xiangfeng, ZUO Dunwen et al. Forming quality forecast for internal threads formed by cold extrusion based on principal component analysis and neural networks[J]. *China Mechanical Engineering*, 2012, 23(1): 51–54.
31. ZHANG Xiaohui, LIU Gang, CHEN Ming, et al. Cutting forces in high speed tapping cast iron by tungsten carbide taps[J]. *Transactions of Nanjing University of Aeronautics& Astronautics*, 2007, 24(02): 94–99.
32. KUANG Lei, HOU Yong. Design of the thread screw electrode[J]. *Die & Mould Manufacture*, 2007(7): 63–64.
33. WANG Zhiheng, YANG Qinghua, HU Xinhua. Derating characteristics of metal cold extrusion with function of chattering[J]. *Journal of Zhejiang University (Engineering Science)*, 2014, 48(11): 1983–1993.
34. FENG Qihan, ZHI Zunli, DE Yuanzhang. Study on step type vibration tapping of superalloy[J]. *Applied Mechanics and Materials*, 2014.
35. KUO K L. Experimental investigation of ultrasonic vibration-assisted tapping[J]. *Journal of Materials Processing Technology*, 2007(192): 306–311.
36. HAN Rongdi, YIN Baolin, CUI Yongpeng. Investigation of small-hole vibration tapping in difficult-to-cut materials[J]. *Journal of Harbin institute of technology*, 2008, 40(01): 50–53.
37. ZHAO Qingrong, WANG Min, ZUO Dunwen. *A study on cold forming of Internal thread in 35CrMo steel*[D]. Nanjing: Transactions of Nanjing University of Aeronautics& Astronautics, 2001.

38. FROMENTIN G, POULACHON G, MOISAN A, et al. Precision and surface integrity of threads obtained by form tapping[J]. *CIRP Annals-Manufacturing Technology*, 2005, 54(1): 519–522.
39. CAO Tengyun, JOHN W. Sutherland. Investigation of thread tapping load characteristics through mechanistic modeling and experimentation[J]. *International Journal of Machine Tools and Manufacture*, 2002, 42(14): 1527–1538.
40. DOGRA A P S, KAPOOR S G, DEVOR R E, et al. Mechanistic model for tapping process with emphasis on process faults and hole geometry[J]. *Journal of Manufacturing Science and Engineering*, 2002, 124: 18–25.
41. XU Jiuhua, WANG Min, JIN Wenlin, et al. Study on cold form tapping of internal threads of superhigh strength steels[J]. *Acta Aeronautica et Astronautica Sinica*, 1993, 14(10): 557–559.
42. XU Jiuhua, WANG Min. Experimental research on forming and strengthening of Internal threads in high strength steels[J]. *Journal of Nanjing University of Aeronautics & Astronautics*, 1996, 28(6): 838–843.
43. LIU Zhaohong, XIA Jianfang, ZENG Nanzhong. Cold extrusion of thin-wall inner-screw[J]. *Metal Forming Technology*, 1997, 3(15): 23–25.
44. GUO Dongming, SUN Yuwen, JIA Zhenyuan. Methods and research progress of high performance manufacturing[J]. *Journal of Mechanical Engineering*, 2014, 50(11): 119–134.
45. MU Shihua, WANG Qiang. Experiment research on pushing temperature of processing and changing rule of the interior whorl[J]. *Journal of Xinjiang University*, 2005, 4(22): 491–495.
46. XU Jiuhua, WANG Min. Combined cut and form tapping of internal threads in titanium alloy[J]. *Acta Aeronautica ET Astronautica Sinica*, 1998, 98(3): 375–377.
47. SUN Xuan, JIANG Chengyu, WANG Min. Application of single chip processor in cold extrusion of internal thread of 300 M Steel[J]. *Aeronautical Manufacturing Technology*, 1996, 1: 25–27.
48. MIEDEMA A R, DE P F C, DE B F R. Cohesion in alloys-fundamentals of a semi-empirical model[J]. *Physica B+C*, 1980, 100: 1–28.
49. TOOP G W. Predicting ternary activities using binary data[J]. *Trans Metall Soc AIME*, 1965, 233(5): 850–855.
50. SHI G L, ZHANG K, LI X G, et al. Influence of deformation twins on mechanical properties and β precipitation of large-cross-section (290 mm×230 mm) AZ80 bar fabricated by "multi-direction forging + extrusion + cold compression" technique[J]. *Rare Metal Materials & Engineering*, 2015, 44(12): 2954–2959.
51. GELLINGS P J, KOSTER D, KUIT J et al. Synthesis and characterization of homogeneous intermetallic Fe-Zn compounds[J]. *Z Metallkd*, 1980, 71: 150–154.
52. LI Zhanming, ZHU Youli, HUANG Yuanlin, et al. Influence of surface integrity on fatigue resistance of the 30CrMnSiNi2A steel after shot peening[J]. *China Surface Engineering*, 2012(5): 85–89.
53. GE Ende, SU Honghua, CHENG Yuanqing, et al. Residual stress fields and fatigue life of cold expansion hole in titanium alloy TC4[J]. *China Mechanical Engineering*, 2015, 26(7): 971–976.
54. ZHAO Hualong, ZHOU Renkui, ZHAO Hongyan, et al. A forming method for improving surface integrity of film cooling holes[J]. *Journal of Aerospace Power*, 2015, 30(3): 649–655.
55. LEI M K, ZHU X P, LI Y P, et al. Significance of surface integrity on high-performance manufacturing by surface modification[J]. *International Journal of Advanced Manufacturing Technology*, 2015: 1–12.
56. DING Y, ZHAO W. Anti-fatigue optimization design of welded structure[J]. *Transactions of the China Welding Institution*, 2008.
57. SHI Shukun, MA Yanling, WU Weidong. Anti-fatigue manufacturing technology of aeroengine part[J]. *Aeronautical Manufacturing Technology*, 2011(5): 26–29.
58. NURUL M A, SYAHRULLAIL S. Surface texturing and alternative lubricant: tribological study of taper die sliding contact surface in cold extrusion process[J]. *Tribology Transactions*, 2016: 1–11.
59. GHASSEMALI E, TAN M J, JARFORS A E W, et al. Optimization of axisymmetric open-die micro-forging/extrusion processes: An upper bound approach[J]. *International Journal of Mechanical Sciences*, 2013, 71(4): 58–67.
60. MIAO Hong, MEI Qing, YUAN Jingyun, et al. Low cycle fatigue and strengthening mechanism of cold extruded large diameter internal thread of Q460 steel[J]. *Chinese Journal of Mechanical Engineering*, 2016, 29(3): 1–8.

Hong MIAO, born in 1981, is currently an associate professor at *College of Mechanical Engineering*, *Yangzhou University*, *China*. He received his PhD degree from *Nanjing Universtiy of Aeronautics & Astronautics*, *China*, in 2011. His research interests include mechanical engineering, anti-fatigue manufacturing and surface technology. Tel: +86-0514-89993750; E-mail: mh0514@163.com.

Cheng JIANG, born in 1993, is currently a Master candidate at *College of Mechanical Engineering, Yangzhou University, Yangzhou, China*. E-mail: jczzxhwl@163.com.

Sixing LIU, born in 1985, is currently a lecturer at *College of Mechanical Engineering, Yangzhou University, China*. He received his PhD degree from *Nanjing Universtiy of Aeronautics & Astronautics*, *China*, in 2016. His research interests include mechanical engineering, anti-fatigue manufacturing and vacuum brazing technology. E-mail: meesxliu@163.com.

Shanwen ZHANG, born in 1983, is currently a lecturer at *Yangzhou University, China*. He received his PhD degree from *Graduate University of the Chinese Academy of Sciences, China*, in 2014. His research interests include mechanical engineering, artificial sun technology. E-mail: swzhang@yzu.edu.cn.

Yanjun ZHANG, born in 1985, is currently a lecturer at *Yangzhou University, China*. He received his PhD degree from *Nanjing Universtiy of Aeronautics & Astronautics, China*, in 2015. His research interests include mechanical engineering, Vehicle Man-machine-environment Engineering. E-mail: zhangyj_204@163.com.