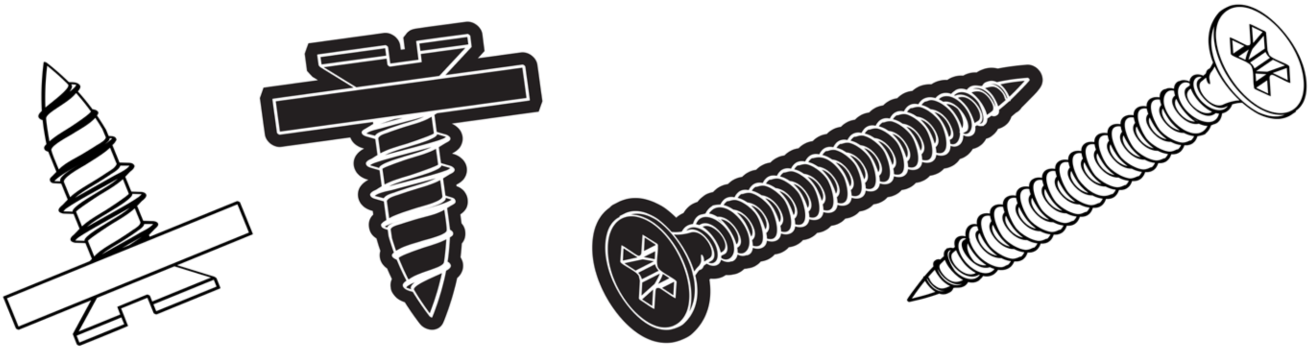

Optimized Thread Geometry to Improve Connection Strength

優化螺紋形狀以提高接合強度

This article analyzes a systematic approach to increasing the strength and durability of fastening connections based on optimization on thread geometry. It is shown that small diameter threads come with a large pitch. Threads of large diameter with a reduced level of defects are fasteners with a small pitch, which, as the main one, is much larger in absolute value. Optimization in the form of unification is proposed to bring the variety of thread geometry to a rational minimum to improve the performance of the fastening connection.

The appearance of carving is considered the beginning of the industrial revolution. Now, threaded connections of fasteners, due to their simplicity, reliability and versatility, are widely used for almost any industrial equipment. At the same time, it is promising for improvement in various fields, including new industries. Improving the design of a threaded connection can be aimed at increasing the strength characteristics without reducing the ductility of the fastener metal due to two great advantages of threads.

▶▶ Advantages of Threads

Firstly, the detachable connection of parts and elements makes it possible to design and manufacture complex machines and structures with expanded production of their modifications. Secondly, dismantling and simple replacement of worn, damaged and destroyed fasteners ensures quick restoration of functionality and extends the service life of machines and structures while reducing the costs associated with their use and maintenance.

▶▶ Systematic Approach in Absence

However, despite these advantages of threads and long-standing use with expanding standardization, a systematic and well-founded approach to increasing the strength of fasteners under static and variable loads is practically absent. This is due to the fact that the potential of material science to increase the strength of fastening joints is, as a rule, limited by the technological deformability of materials. When both the design possibilities of thread profile geometry have a more promising potential for their strength optimization, it logically follows from an analytical consideration of the inconsistency and irrationality of standards for the geometry of fastening threads.

Used for several hundred years and standardized since the 19th century, fastening threads are the same from a theoretical point of view, since they have common construction principles and are characterized by almost the same set of geometric parameters. A screw thread in technology is a group of alternating projection and depressions of a certain extent on the surface of a body of revolution, which is the main geometric element of a threaded fastener. At the same time, threads for connecting bolts, screws, studs and nuts can be considered as an inevitable design defect such as an inclined screw notch, which has a certain helix angle and can be subject to the combined effects of a combination of shear and pullout stresses. Typically, the value of such a structural defect for a fastener made of high-strength steel is taken to be the working height of the thread profile, calculated from the pitch and radius of curvature of the thread root. It is obvious that, for example, a high and overloaded protrusion in the form of an equilateral triangular profile can lead to the formation of a crack in the thread root and failure of the fastener under tension or bending conditions, since the thread of the connection is in a complex stress state and is characterized by a high stress concentration, especially in the first turns, the most likely sources of deformation and destruction. The influence of stress concentration is taken into account by the theoretical stress concentration coefficient in relation to the maximum tensile stress in the most loaded zone of the thread to the nominal stress, taking into account the internal and average diameters of the thread. It can be noted that calculations of the theoretical stress concentration factor in the thread of a connection, for example, for the main connector of a nuclear power reactor vessel, are carried out provided that its minimum value is not less than 4.0.

▶▶ *Systematic Assessment in Absence*

In numerous reviews and studies of sets of fastener performance characteristics for resistance to deformation and fracture under stationary and variable loading of the connection, there is still no systematic assessment of the influence of thread geometry taking into account the unfavorable load distribution along the turns of the connection. It can also be noted that the practice of thread geometry, which has existed for about 200 years, in particular, the inch and metric threads of Whitworth and Sellers, respectively, has not undergone fundamental changes, despite the development of screw-cutting lathes and other industrial technologies, starting from the late 18th and early 19th centuries. For example, in Germany at the end of the 19th century and in the USA in the second half of the 20th century, the number of national standards was very large: 11 thread systems with 274 varieties and about 8 thousand standards (taking into account special-purpose fasteners, up to 2 million varieties that did not become the subject of system optimization of thread geometry).

According to GOST 24705-2004 (ISO 724: 1993), for a metric profile thread for a nominal diameter, for example, M20 or M48, instead of 3, 4 or 5, as many as 6 options are given for a practically ranked series of large, medium and small thread pitches. For these threads with the so-called normal thread pitch, the ratio of diameter to thread pitch is in the range of 8.0…9.6. Also, according to the standard, the diameters M140 and M180 for the case of a main or large pitch of 8.0 mm (which is practically not used and at the same time is the first designated nominal pitch) give a ratio of diameter to pitch in the range of 17.5…22.5 , which is approximately 2 times more than for threads of smaller diameter M20 and M48. This indicates that the designation of the geometric parameter of the thread as large or main, as well as small, is not objective enough and is not justified in any way. Because **standard large diameter threads with the largest pitch are essentially fine pitch threads and are less defective than smaller diameter threads. But the M20 and M48 threads have a very large pitch geometry and are more defective due to the larger relative height of the thread profile. It is not difficult to see that the lack of consistency and unjustified diversity of thread geometry within the framework of a non-evolving standard contradicts the logic of ensuring the strength and performance, including resistance to brittle fracture, of a threaded connection.**

In the past, mainly in the 19th and 20th centuries, fastening threads were designed for stationary and moderate loading conditions and the use of coarse pitches was structurally and technologically acceptable. Currently, fastening threads have become more often used under higher static tensile loads, as well as under conditions of low- and high-cycle fatigue loading, not only in air, but also in various corrosive environments. This initiated the development of fastening materials that combine increased strength with a simultaneous increase in corrosion resistance through alloying and the use of surface strengthening and protective coatings. At the same time, despite this, the likelihood of a metallurgical, power or corrosion defect such as a small crack in the thread due to significant defects in the thread itself and high uneven load distribution along the turns, including the growth of this crack taking into account the height of the thread profile, remains significant. **It should be noted that the overload of the first working thread can be up to two times higher than the load of the free thread. A small thread pitch instead of a large one due to the reduction of stress concentration, uneven distribution of load along the threads and their more effective unloading by adjacent threads, allows increasing the resistance of fastening threads to static, cyclic and brittle fracture.**

▶▶ *Unified Thread Geometry Options Await Development*

For example, the transition from M12x1,75 stud threads with a thread radius of 0.14mm to the M12x1.0 version with 0.12 mm made of 38KhN3MFA steel with a yield strength of 900 N/mm^2 made it possible to increase the resistance of the nut connection to low-cycle fatigue based on 10,000 cycles before failure by 25% based on stresses in the net cross-section of the stud. In terms of the number of cycles, the durability of the fastening joints increased by 2.5 times at a maximum cycle voltage of 700 N/mm^2. Photo 1 shows fragments of the fracture of the studs, where it is clear that for a pitch of 1.0 mm, the formation of a viscous and neck-shaped fracture surface took place. This type of fracture is close to the classic static axisymmetric fracture of a smooth cylindrical sample. A small pitch, as it is more technologically advanced, in production conditions allows to reduce the costs of cutting tool wear and waste, as well as increase its durability when rolling threads. The use of small steps should be limited by the resistance to destruction of the threaded connection by "chain" shear under conditions of collapse or cutting of thread turns under static loads. Thus, we can conclude that **it is advisable to develop new and unified thread geometry options to improve the performance of the fastening connection. The reliability of more loaded and maneuverable machines and structures will be ensured through system optimization of a set of thread geometry parameters.**

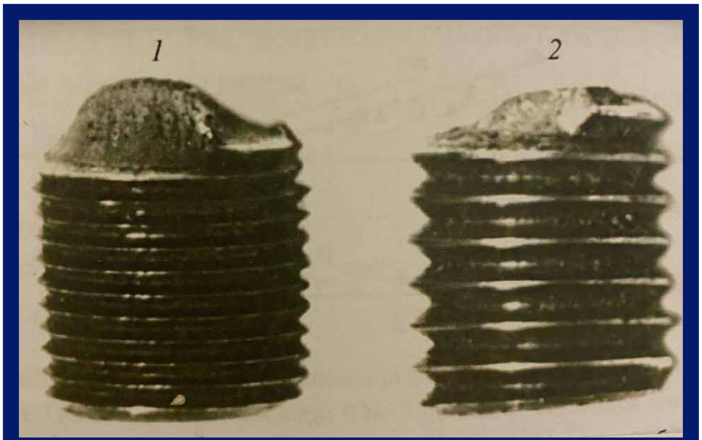

Photo 1: An example of the influence of metric thread geometry on the resistance to low-cycle fatigue failure of a M12 stud-nut fastening connection: 1- pitch thread 1,0mm; 2- pitch thread 1,75mm. The material of the studs and nuts is steel 38KhN3MFA with a yield strength of 900N/mm^2. ■

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