~ Fastener Expert 101 ~

Thread Geometry

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Introduction

Screws are used in various industrial products ranging from machinery, buildings, precision machines to electronics. The purpose of using screws is versatile, and various shapes of screw components are being used. Then here comes a question: "What is the biggest characteristic of screws?" I would tell you it is "the spiral structure of the threads". I would like readers to recall various types of screws. The "spiral structure" in which male threads engage with female threads is processed onto every type of screws. Thanks to threads, screw fastening is possible, and loosening a screw by reverse turning is made possible as well. Unlike welded joints and rivets, screws are a highly flexible machine element in which fastening and loosening is possible. Although the loosening of a screw is one of the biggest pains for technicians, the capability of loosening is a characteristic of screws. Thanks to this capability, it is possible to reveal the fastened part for maintenance and inspection and later assemble it again.

Utilizing elementary mathematics to explain "thread spiral", this article aims to provide screw-related technicians with an opportunity to review thread geometry.

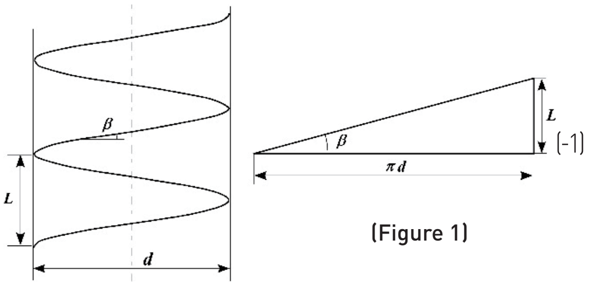
Thread Shape and Spiral Structure

Circular motion is the movement of an object around a fixed point on a surface from an equivalent distance. If the object moves in circular and axial direction at the same time on a cylinder surface, it forms a trail of a "spiral". If we name the cylinder's axial direction as the z axis, name the cylinder's diameter as d, and name the circumferential angle along the circular direction as θ, we can demonstrate the shape of the spiral with the following formula.

$$x=\frac{d}{2}\cos\theta,\ y=\frac{d}{2}\sin\theta, z=\frac{d}{2}\theta\tan\beta \quad (1)$$

Figure 1 is the spiral drawn using the formula above. If we wind a right triangle with catheti (legs) πd and L (together forming a right angle) around a cylinder of diameter (d), the hypotenuse (the side opposite of the right angle) of the triangle turns into a spiral. If we name the spiral's distance of travel in one rotation as the Lead (L), and name the angle formed by the spiral and horizontal surface as the Lead Angle (β), we can demonstrate the relation among d, L and β in the following formula.

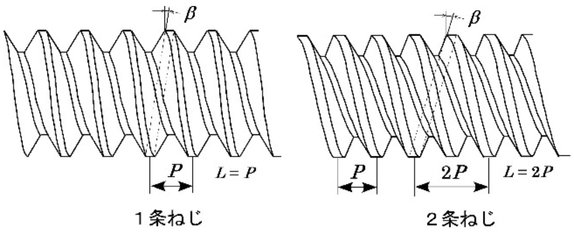
$$\tan\beta=\frac{L}{\pi d} \quad (2)$$



(Figure 1)

Based on that, if we wind and overlay triangles and trapezoids around the cylinder, triangle threads and trapezoidal threads are formed. **Figure 2** demonstrates the shape of single and double triangle threads. The distance between two corresponding points on adjacent threads is named Pitch (P), and the relation among the number of thread (i), Pitch (P), and Lead (L) is demonstrated in the following formula.

$$L=iP \quad (3)$$

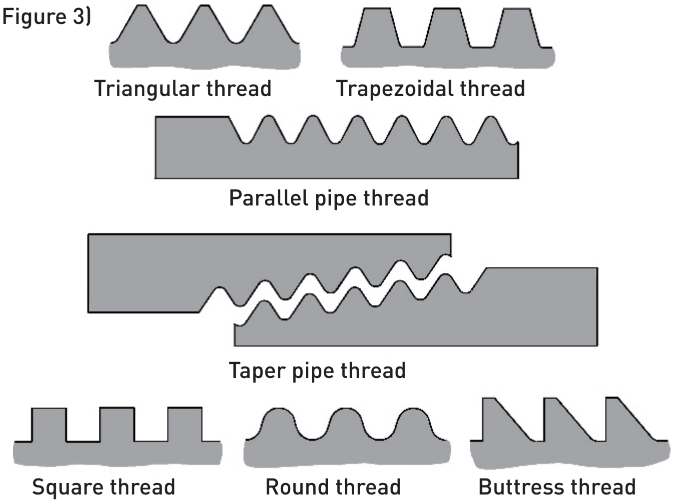


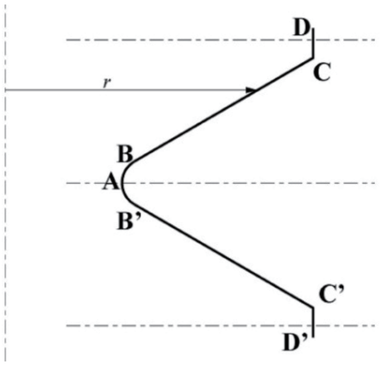
(Figure 2) Single thread Double thread

Certainly, in a single thread the Pitch (P) and Lead (L) are equivalent. Multiple threads are sometimes used for motion transmission to utilize the feature that they travel longer distance in one rotation. In terms of fastening, starting with their existence on feed screws used for emergency shutoff valve, multiple threads are also applied on cosmetics bottle caps because they only require fewer turns to fasten. Such multiple threads have various characteristics because they have bigger lead angles. Compared with square thread and trapezoidal thread, triangular thread is less likely to loosen. Meanwhile, the reason that thread performance efficiency is low is because the flank of the thread is 30 degrees inclined to the cross section perpendicular to the axis of the thread. On the other hand, the bigger the lead angle, the higher the thread performance efficiency. Accordingly, large lead angle results in high efficiency. In the meantime if we utilize the features of triangular multiple threads which have proper anti-loosening function, it will be possible to come up with a brand-new motion transfer mechanism and stop mechanism, and we can anticipate a broader application range for multiple threads.

The Shapes of Thread Cross Section

Figure 3 demonstrates various kinds of threads whose shapes are usually represented by cross sections along the thread axis. Then, what is the shape of the cross section perpendicular to the thread axis? **Figure 4** (a) and (b) demonstrate the shapes of the cross sections along and perpendicular to the axis of triangular single thread. In terms of a half pitch thread, the shape of cross section on the thread axis demonstrated in **Figure 4** (a) can be divided into 3 portions: the root of the thread (A-B), flank (B-C), and crest (C-D). If we unfold the distances (r) from the thread axis to respective portions onto the cross section perpendicular to the thread axis, we will get the "actual cross section shape of the thread" as in **Figure 4** (b). The lower portion (A-B'-C'-D') of the cross section is in linear symmetry to the x axis. As such, regardless of the thread shape (such as triangle or trapezoid), in terms of single thread, if we unfold the cross section shape of a full thread onto a flat surface, we will get the actual cross section shape.


(Figure 3)



(Figure 4 [a] , [b])

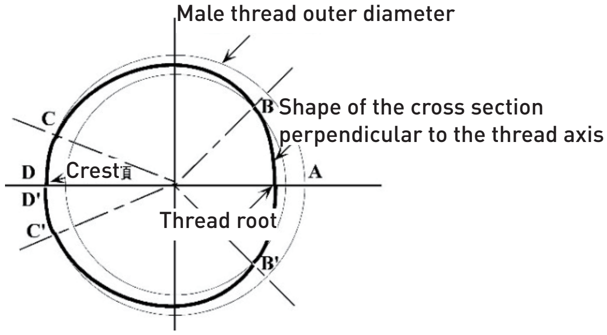
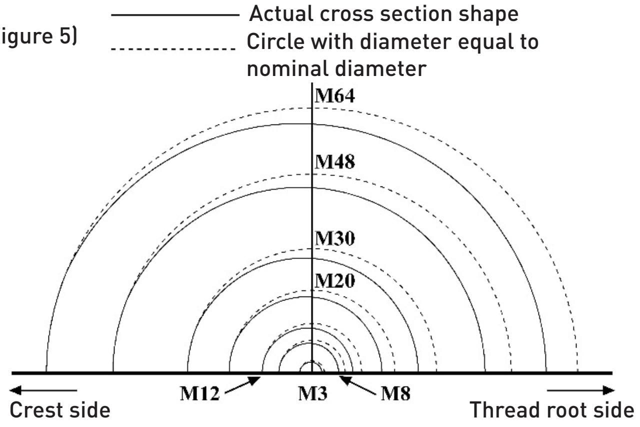


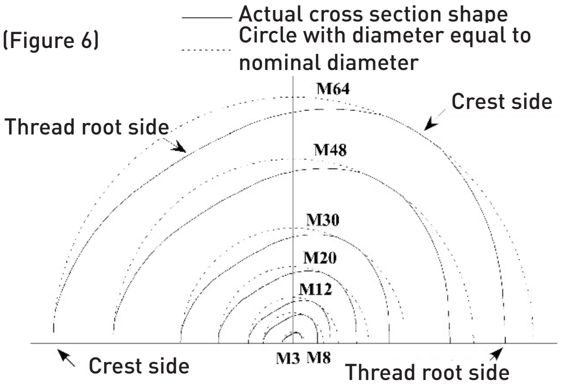
Figure 5 demonstrates the actual cross section shape of a metric coarse thread, with the thread's nominal diameter as the parameter. The solid lines demonstrate the actual shape, and the broken lines demonstrate the circles formed by nominal diameter (d). The smaller the thread's nominal diameter, the actual cross section becomes less likely to form a circle. The reason is because the proportion (P/d) between Pitch (P) and nominal diameter (d) turns smaller if the thread diameter turns larger. **Figure 6** demonstrates the actual cross section shape of triple triangular and trapezoidal threads, with the thread's nominal diameter as the parameter. Additionally, the area of these actual cross

section shapes can all be demonstrated via elementary functions and available via simple calculation.

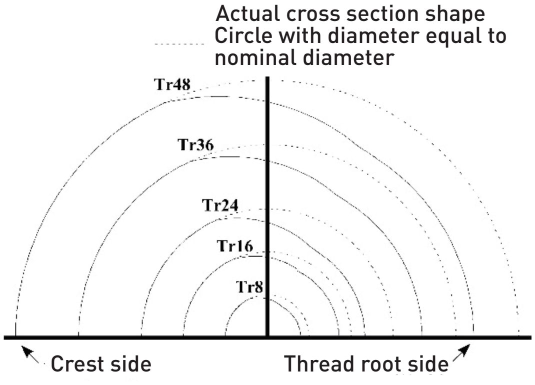
(Figure 5)



(Figure 6)



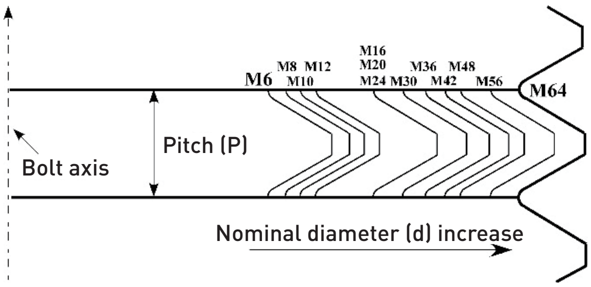
(a) Triple thread



(b) Trapezoidal thread

The Dissimilarity of Threaded Components

Regardless of nominal diameter, the basic shapes of threads are the same. Threaded components, in which the threads wound onto the outer or inner surface of cylinder, do not share similarity in shape because the proportion (P/d) between Pitch (P) and nominal diameter (d) turns smaller if the nominal diameter turns larger. **Figure 7** compares the shape of male coarse threads ranging from M6 to M64, whose pitch sizes are all drawn with the same amount of length. Based on the figure, we understand that the pitch relatively turns smaller as nominal diameter turns larger. Such dissimilarity in threaded components is the major reason for the change of fastening strength and fatigue strength for varying nominal diameter. In other words, the logic of strength evaluation on small diameter threads cannot apply to large diameter threads. Particularly in terms of pitch, the maximum value is basically 6mm. Even in the case of large threads with nominal diameter over 100mm, relatively smaller pitches are used. Consequently, even if the axial stress during fastening is equivalent and the bolt's stress change resulting from external force is the same, there still are cases that show mechanical properties different from those of small threads.

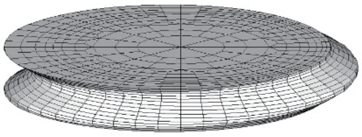


(Figure 7)

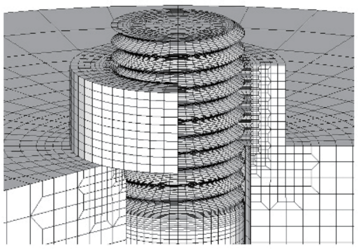
Computer Models Utilizing the Actual Cross Section Shape of Threads

Ever since ancient Japan there has been a type of candy called "Kintaro ame", a cylindrical candy made so that Kintaro's face appears in the same shape wherever it is sliced. As in this example, we can think of the shape of thread as a "twisted Kintaro candy". In other words, if we rotate the "actual cross section shape" demonstrated in **Figure 5** and 6 while moving it in axial direction, we will be able to correctly recreate thread shape. **Figure 8** (a) demonstrates the computer model of a full male thread made via the above-mentioned method. **Figure 8** (b) and (c) are respectively the full fastener model of a bolt and the detailed mesh pattern of a nut model. **Figure 9** (a) and (b) are respectively the finite element models of male triple thread and taper pipe thread. With the use of these models, mechanical properties are being made clear, including the properties of thread fastening, stress concentration at thread root, and stress amplitude at thread root that greatly affects fatigue strength.

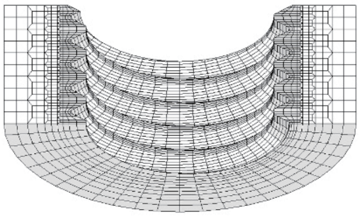
(Figure 8【b】,【c】)



(a) Male full thread

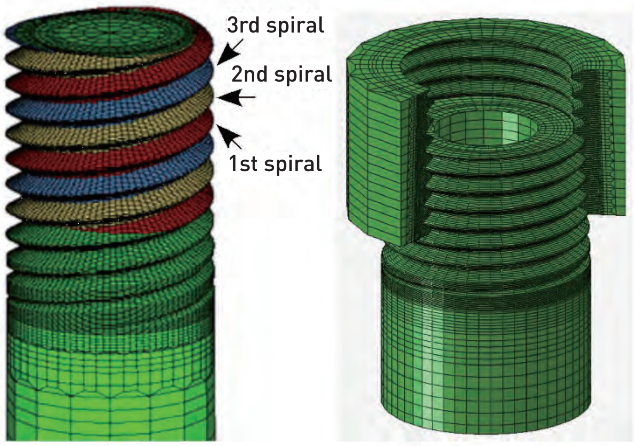


(b) Full fastener model of a bolt



(c) Mesh pattern of a nut model

(Figure 9【a】,【b】)



(a) Triple thread

(b) Pipe taper thread

Final Words

By reviewing thread geometry, this article demonstrates the relation between actual cross section shape and nominal diameter for various types of screws, as well as the fact that threaded components with different nominal diameters do not share similarity. In addition, as the article demonstrates, if we utilize the actual cross section shapes, complete recreation of the shape of threaded components via computer models as well as the elucidation of various mechanical properties are possible. In another time I would like to introduce the effect of threaded component dissimilarity onto various mechanical properties. ■

Reference

1. Toshimichi FUKUOKA, "Threaded Fasteners for Engineers and Design – Solid Mechanics and Numerical Analysis –", CORONA Publishing Co. Ltd.

About the Author:
Toshimichi FUKUOKA

The author was specialized in the study of thermal stress using numerical analysis in graduate school. Afterwards, he taught in Kobe University of Mercantile Marine, and acquired a Ph. D. in Osaka University for the study on mechanical behavior of screw threads by finite element analysis.

In 1988 he spent a year in University of Michigan studying computational mechanics; in 1997 he was promoted to a professor for Kobe University of Mercantile Marine; in 2003 he was a professor for Kobe University.

He is a fellow of Japan Society of Mechanical Engineers and has published lots of papers in the JSME journal. Based on those achievements, he recently published a book entitled "Threaded Fasteners for Engineers and Design - Solid Mechanics and Numerical Analysis -"

Toshimichi FUKUOKA is a renowned scholar in the Japanese fastener industry and is considered a pioneer of Japanese fastener research. In addition to writing many papers and publishing multiple books, he was invited by The Japan Research Institute for Screw Threads and Fasteners to write papers. Furthermore he was once interviewed by athome-academy.jp. He wrote many easy-to-comprehend works of knowledge for Japanese fastener technicians. We believe his contributions to Fastener World Magazine will bring Japanese fastener viewpoints to our broad American, European, and Asian readers.