APPLICATION TECHNOLOGY

FASTENING SOLUTIONS FOR ALL INDUSTRIES

The dimensional measurement of fasteners

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As an engineer, the opportunity to solve a problem provides great delight. Where a solution already exists without knowing the problem – well that poses an additional challenge. Whilst tracking some elusive information online, I recently came across a genuine bona-fide 250 year old mystery known as, Roman Dodecahedrons.

Dated the second to fourth centuries, over 100 of these strange objects have been found – one being this year (example pictured right). They consist of 12 sided pentagons and have face widths between 4cm and 11cm. Holes of various sizes exist at the centres of each face – most faces being inscribed by concentric circles, and/or straight lines. At each of the 20 vertices are mushroom shaped balls of around 6mm in diameter. Virtually all Roman Dodecahedrons found to date are investment cast in a copper alloy and very strangely, have only ever been found in countries on or north of the Alps.

Since no documentary evidence or artwork regarding the purpose of these objects has been found, their existence has opened the floodgates to conjecture. For those readers who might be interested in history, and perhaps in solving puzzles, such objects present a true 'engineering' challenge.

Dimensional measurement

Whilst following various threads regarding Roman Dodecahedrons, I came across a reference of the Roman use of physical standards. Apparently, in the Temple of Jupiter in ancient Rome resided the Standard Amphora. This, like the standard Metre/Imperial Yard kept in Paris and London respectively, represented the final arbiter on which all commercial matters of such dimensions were determined.

Interestingly, one of the many suggestions that have been proposed for the application of Roman Dodecahedrons has been that of GO – NO GO gauges for

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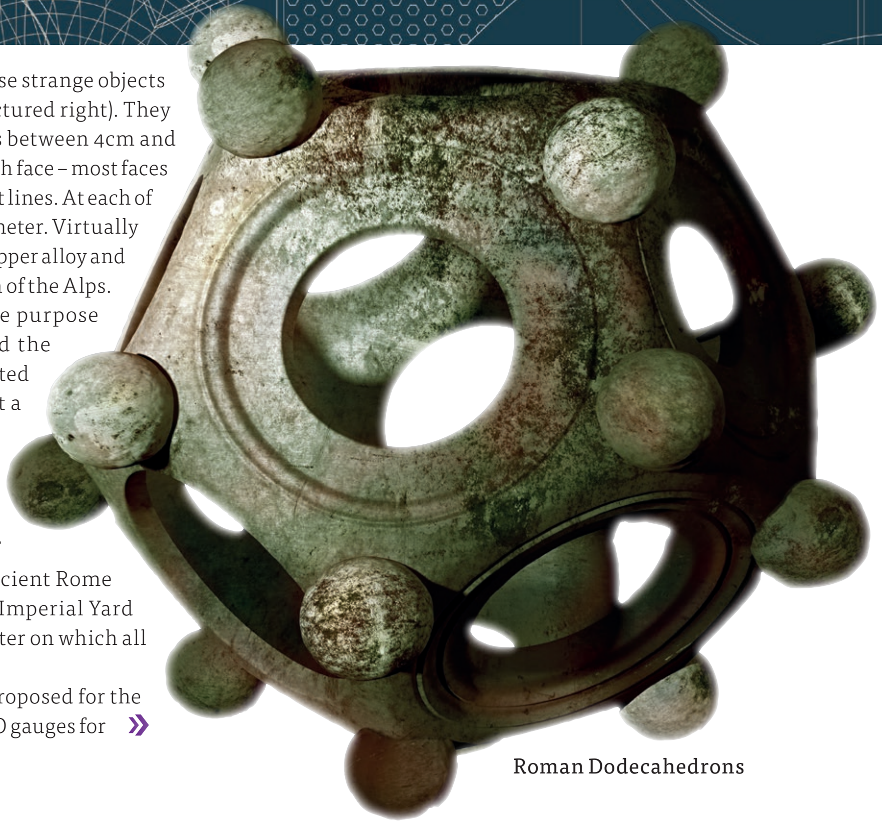
Roman Dodecahedrons

sizing pipes. Despite what mathematicians and physicists may tell us, the 'real' world has only three dimensions. Yesterday has gone, tomorrow hasn't happened, so we all exist in the here and now. Essentially, time is only a method of determining trends.

Using the Cartesian axes X, Y and Z provide rectilinear directions for the measurement of length. Rotation about a point on a plane provides a means to measure angles. The use of 360 degrees into which we divide a circle is simply our adoption of the ancient Sumerian number system which, unlike our use of the base 10, operated with a base 60. Rotation of a circular plane through 180 degrees produces a sphere.

All rectilinear measurements are made using comparative methods. In days long gone, the 'standard' against which everything was compared could have been:

- A King's digit, arm, foot, etc.
- The length of a stable material having uniform cross section and measured between scribed lines (like a rule).
- By measuring the distance between its perpendicular ends (as in the standard metre/yard).

Today, the accepted international standard unit of length is the metre (m) defined in terms of the speed of light. For a fastener, measuring its length and diameter is easy depending on the accuracy and repeatability required. However, perfection – if that is possible – can only be obtained if it lies within the bounds of acceptable error (the tolerance). Measuring a length using a steel rule can be determined within the thickness of its scribed line. Better accuracy can be obtained if the measuring device has a vernier scale to sub divide the tolerance.

> Introducing AI into fastener manufacture could significantly benefit the whole of the supply chain…"

With greater accuracy (closer tolerance), what now becomes apparent is the accuracy of the measuring device itself. The 'rule of thumb' is that the device which is used to obtain the measurement must be capable of providing an accuracy of at least an order of magnitude (ten times) better than the measurement required. Very soon, the equipment used to provide the measurement itself requires calibration; a service provided by an 'authorised' metrology laboratory.

Where fastener manufacture involves cold forming, the tooling, either single or multi stage, will require the same 'rule of thumb' regarding an order of magnitude increase in accuracy relative to the part being produced.

Whilst dimensional tolerance is an absolute requirement for linear measurement, this on its own, is not sufficient to obtain component functionality. For example, where the diameter of a circular long rod or pin may be within tolerance everywhere along its length, it could fail to fulfil its design function if it was bent and jammed inside a mating long hole. It is for this reason that to fully define a component, attributes of geometric form and their 'tolerance' must be included.

The geometric tolerance of any and every component requires all its surfaces to lie within parallel imaginary surfaces, which define its dimensional boundaries. So, for any flat surface, two imaginary planes are created within which the surface must lie. These produce what is known as the maximum or minimum material condition. This is an essential requirement on every component drawing where, in order for it to achieve its function, its surfaces must be parallel, square, concentric, etc, to some datum surface or axis. Failure to ensure such information, including surface finish, material conditions, etc, will severely compromise the manufacture of any design – since those who have to work to a drawing can only guess at what they don't know and aren't informed about.

Implications of design tolerance

It is an accepted fact that 95% of the cost of a component is incurred at the design stage. A blanket use of tighter tolerances where nominal values will suffice has zero effect on functionality and can introduce wholly unnecessary costs in manufacture. This can be particularly expensive if the interrelationships between the designated geometric tolerances specified on the component drawing require expensive (and perhaps unnecessary) instrumentation to inspect.

Within the fastener manufacturing ladder there are companies that often have a substantial history serving local and wider regions of the same business sector, such as automotive, aerospace, construction, rail, etc. These businesses, producing audited 'standard' products, have invested in and meet all the required 'quality' certifications demanded by customers. Globalisation, both of their customer base, and the industry they serve, has brought with it significant outsourcing and imports causing major restructuring of their business. Those who survived this turbulence were often targeted for acquisition by overseas manufacturers who sought to refashion their own manufacturing model.

The net result of this fastener manufacturing realignment, and the demands required to meet the quality needs, has created a new breed of sharper, more focused producers who have staff trained to operate inside a largely digital environment.

The introduction of Artificial Intelligence

The golden key to the current world of 'instant' is information. The bringer of the 'golden key' is AI. Go to your web browser and without it being requested, an AI package of your browser's choice, will ask you to ask it a question. My own attempts to seek answers to very obscure questions has resulted in providing only child like responses, which I already knew. The reason, because all AI systems are simply only rapid learning processes. A very recent example has been the US$40,000 prize won by a student for finding a method to read text written on a Roman Scroll and buried in the first century volcanic eruption of Vesuvius. His methodology, to view an image and then get the AI program he wrote to repeatedly improve it until it was legible. In short, like all methods of analysis, it requires data to work on.

In fastener manufacture almost everything is produced in batches. Fully automated systems, where possible, are preferred to those involving humans. Once set-up and running under controlled conditions, an automated system will only stop (fail) when:

- It has nothing more to process.
- Its power is cut off.
- The 'measured' product being produced and monitored trends toward its statistical warning or action limits.
- A breakage or jam occurs.

A human operator will experience the same situation and produce the same result but being a free spirit could also introduce all manner of unnecessary uncontrolled variations into what, in essence, is a simple system.

Introducing AI into fastener manufacture could significantly benefit the whole of the supply chain through the analysis and prediction of likely occurrences. Focusing only on the manufacturing side, this could and should begin with a deep dive into the 'as received' input material. All material suppliers have their own 'operational tolerances', which

begin with material specification, processing routes, property data, etc. To ensure their own comfort zone, every supplier desires such tolerances to be as wide as possible and will increase the price if the customer requires them to be tighter.

It is an acknowledged fact that the wider the tolerance band of elements within a material, and/or the greater the variation in the processing route, the higher the probability of obtaining variability of the product.

For their part, fastener manufacturers – like all businesses – seek to extract the maximum value from their labours for the minimum input cost. This often means pushing the envelope on machine use (higher force, larger size, faster speeds), labour skill sets, set-up times and maintenance downtime.

All progressive fastener companies apply in-process monitoring to record the manufacturing process. By introducing AI to analyse this data, a detailed blow by blow 'real time' account of the underlying strengths and weaknesses of the system will be revealed automatically. This will show, in startling clarity, where efficiencies exist and most importantly where they can be gained.

This includes greater qualification of the input material; direct processing evidence of a machine/setter's performance in meeting both quality and output targets; the sensible revision of component drawing tolerances to match its 'in-service functionality'; ease/cost of inspection; and the on-line sharing of quality improvements gained by the implementation of AI.

Actions taken on these aspects will produce greater control and improvement of any system.

Conclusion

In the days when industrial towns shut down for their annual holidays, it could be a lonely place to live if you didn't go away. In an increasingly digital world, the same could be said for those reluctant to accept the inexorable changes taking place. For all fastener manufacturers, the goal to be able to make a batch size of one as cost effectively as a batch of thousands, is something to strive for and which realistically may never be reached.

However, the customer requirement for zero defects is here and obtained through judicious use of 100% inspection. If AI methods could be used and trained to achieve this goal through process improvement, then both quality and profits would increase.

AI might also reveal the answer to a puzzle which this author came across at a fastener workshop many years ago. The technical director of a company hosting the meeting gave a non-confidential presentation to a group of his peers from other 'competing' fastener companies. In the presentation, they said they "introduced a new coil to the machine and found it wouldn't run satisfactorily". 'What did you do then?' he was asked. "What we always do," he replied. "We turned it round and used the other end and it ran well." This answer was accepted by sagely nods from many of those attending. However, when asked by this author why this should be, no one, including the wire producers who were also present, could explain.

As for my take on the Roman Dodecahedrons? Remember, none have ever been found around the Mediterranean, only on or north of the Alps. As an engineer, I wondered how I might produce a similar component using the lost wax process and having access only to rudimentary tools. Whilst reading this, please take a moment to consider how complex the geometry of a dodecahedron is (these are hollow) and the measurements that would be needed to achieve it.

It is worth noting that in Roman times moving goods by water was ten times less costly than moving them on land. Also, very clearly, there would be few commercial ventures that considered taking wheeled transport from the rest of the Empire over the Alps.

Julius Caesar stated that people in Gaul had fast chariots and from archaeology we know that bronze and iron age folks north of the Alps were fine craftsmen.

From gathering information off the web concerning the hole size of around 80 dodecahedrons, I found 46% were in the range 12mm – 16mm diameter and 44% between 10mm – 12mmm and 18mm – 24mm (typical of a bell shaped distribution). In terms of the range of hole size per dodecahedron, 12% are within 9mm between largest and smallest, 68% within 17mm and 20% within 26mm.

From this data and without the use of AI (as yet), my own suggestion (you will read it here first) is that Roman Dodecahedrons were used as a gauge by wheelwrights to determine the size of lynch pins required to keep a wheel on its axle (between 97mm to 113mm diameter). Long ones would be required to pin wheels to rotatable axles or shorter ones to fix the position of wheels on to fixed axles. The smaller 12% range holes for use on lighter vehicles, 68% for general purpose vehicles and 20% for heavy goods over rough terrain. And the 20 small balls? Well, they could have three purposes. One to prevent damage to the centre hole, second to have something to stand on, thirdly and most importantly, to provide a means of grip for the wheelsmith's hands, which might be covered in animal fat.

Whilst it is perfectly possible that these strange objects may have had a non-utilitarian cultural existence as decorative or religious objects, if they did fulfil a practical function, then the laws of probability suggest their application could have been for the process of creating yet another of mankind's most ubiquitous products – a fastener. Remember the traditional ten in one dog bone (dumbbell) shaped hexagonal spanner used for bicycles – well, they are still made and sold today. ✚