MANUFACTURING DOCUMENTATION – THE IMMEDIATE OUTCOME OF DESIGN

Colin LEDSOME
Consultant

ABSTRACT
Whatever the product, whatever the market, the immediate aim of the design process is to produce a set of documents, mainly drawings, which describe the product unambiguously to the maker in a mutually agreed language. Over the last century, various drawing standards have been developed in different parts of the world. Some larger industries, or even individual companies, developed their own drawing standards. In the late 1980s, new thinking began to emerge, which has led to a broad international agreement on common drawing and dimensioning standards and particularly tolerance specifications. The new symbol based tolerance system has been demonstrated as more cost effective and less subject to interpretation than earlier systems. It also allows drawings to be understood in different countries, even when the participants do not have a common language. Much of the world is now in the process of adopting these standards especially where manufacturing is “outsourced” to other countries. These developments must be reflected in the education and training of designers of all persuasions, both in courses for novices and training for experienced designers.

Keywords: Engineering drawing standards, Technical/Geometrical Product Specification

1 EARLY HISTORY

The first manufactured articles developed very conservatively. If something worked, there was no incentive to change it. It took millennia for small changes and improvements to be made in the design of arrowheads, fish-hooks, pottery and the other few artefacts we can find. When they did come, these changes were probably made by the person who made it, so drawings were not needed. Whatever worked was copied faithfully by later makers. A lack of technical appreciation meant that later makers were reluctant to change even the smallest details in case of failure. In 1854, Commodore Matthew C Perry of the US Navy, with a small fleet of steam ships, became the first new western contact with the Japanese Empire for two centuries. They found that the Japanese Navy were equipped with cannon, which were exact copies of 16^{th} and 17^{th} century European guns, including the dates cast onto the barrels.

Only when the product became big and complicated were drawings and models needed. Pyramids were pretty big and historians wondered for a long time if there were any construction drawings. Then an early pyramid was actually dismantled and, as stones were removed, detailed sketches for each layer were found on the stones of the layer below. Perhaps the final details were not fully considered until the lower stones were in place. A sketch by Michelangelo was found recently, dated to 1563 the year before he died, which is a drawing of some construction details for the stonecutters working on the dome of St Peter's Basilica. [1]

The few design records of palaces and cathedrals which do exist show detailed pictorial views with cutaway and scrap sections and details where the construction was more complicated. In some cases, such as St Paul's in London, large models still exist with removable sections and viewing points so that details can be seen. Even so many of the final details and dimensions must have been decided by the masons, carpenters, plasterers, painters, and other craftsmen doing the work, in discussion with the architect and each other. Even today in the construction industry, many of the details, like plumbing and wiring routing, are left to the person putting it in, particularly on domestic and other small buildings.

In the 15th and 16th century world of pumps, windmills, siege engines and other mechanical devices, there were pictorial and written records, notably Agricola [2] covering the mining industry, and others, detailing the devices in use. The basic technologies were laid out in a widely published book of drawings by Ramelli [3] in 1588, but rarely are the design drawings themselves, or earlier sketches, available. As in the construction industry, the secrecy of the crafts guilds, and the small numbers involved in making each device, made formal drawings unnecessary once the overall requirements and dimensions were agreed. Any sketches made were probably not thought worth keeping.

Only when it became necessary to produce interchangeable parts for identical machines do drawings begin to be seen as important. This happened with the inventions which introduced mechanization into the weaving industry in the UK. Arguably, the industrial revolution began in 1589 when William Lee introduced his knitting frame, which allowed hose to be knitted 20 times faster than by hand. The weaving industry pioneered the use of intricate machinery with Hargreaves' spinning jenny, Arkwright's water frame over the next two hundred years and drawings exist of some of their details. The importation of raw cotton increased from under 8 million pounds in 1780 to 620 million pounds in 1850.

Early in the 19th century, Marc Isambard Brunel designed pulley blocks to be mass produced for the Royal Navy. Henry Maudslay produced the manufacturing machinery and by 1808 the factory at Portsmouth was producing 130 000 blocks a year. Ten unskilled men did work which would previously have required 110 skilled men saving £17 000 a year for an outlay of £54 000. Some of the machinery was in use for 145 years and is still on display at Portsmouth.

This was paralleled by the expanding railway network and the mass production of firearms in the USA. These in turn generated the need to improve the accuracy of measurement, the standardization of key parts, such as screw threads, and an appreciation of the importance of dimensional tolerance. Joseph Whitworth became the first person to produce a machine to measure to one millionth of an inch, and his measuring standards spread throughout manufacturing industry.

The other major incentive to keep a record of the important details of a mechanism was the need to protect intellectual property rights with patents. Early patents show pictorial sketches of the critical parts of a device and describe how they interact. As technologies became more complex, so the drawings became more detailed to show the key components.

2 THE FIRST NATIONAL STANDARDS

The British Standards Institution was formed in 1901, closely followed by similar organizations in the major industrial countries. It produced the first drawing standard, BS 308 in 1927. This slim booklet remained unchanged until the 1950s, when it expanded to a detailed guide to drawing office practice. In 1972, it was enlarged to 3 volumes to incorporate several different ways of specifying tolerances. The different forms were applied appropriately to different methods of manufacture. It retained the status of a guide and many industries and larger companies had their own versions with extra features appropriate to their circumstances. Other countries followed a similar path.

The International Organization for Standardization, ISO, was founded in 1947. The post war expansion of international trade encouraged the use of common standards particularly where similar products were being made for several countries. However, with imperial and metric measurement, 1^{st} and 3^{rd} angle projection and differing paper sizes, to add to industry and company variations, movement towards common drawing standards was slow. Where common standards could be agreed, national standards began to make more reference to ISO standards. As major industries moved to metric measurements and common CAD systems became more established, basic drawing became more standardized, but tolerance specification remained a subject of much debate.

3 THE NEW STANDARDS

Discussions began in the 1980s in ISO committees to find a common approach. The current methods of specifying tolerances were found to be ambiguous and subject to interpretation, particularly when applied to parts produced on the increasingly common machining centres. The exact positions of datums and the implication of theoretically exact points and planes caused confusion. A new system gradually evolved, which removed most ambiguities, known as Geometrical Product Specification, GPS. It was soon found that the same level of fit could be achieved in many cases with less exacting tolerances. This has led to a significant reduction in manufacturing costs for many products. Commonly understood symbols were established to avoid translation difficulties, particularly as components and sub-assemblies are now often made in a variety of countries.

It has not been universally accepted. There are some small but fundamental differences between the ISO standards and those in the USA. The ISO system works on the principle of independency, where each tolerance requirement is assumed to be met separately unless specifically indicated. The American system adopts the principle of dependency where a tolerance link is assumed. Thus, while most of European industry, and its major suppliers in China, India, Japan and elsewhere, have accepted the ISO approach, the American industrial sphere of influence, particularly in aerospace, remains with their system. Each has some advantages, so they are not easily reconciled. Since most CAD software originates in the USA, some systems were slow to catch up with the ISO symbol set, but most now allow a choice of modes.

A number of ISO standards became established based round GPS. It became clear that there was a mismatch between the venerable BS 308 and the ISO approach, which would require more than a simple revision. A new standard: Technical Product Specification BS 8888 replaced BS 308 in 2001. This time it is a specification rather than a guide, so any documentation which conforms to it must cover all of its provisions. It is also a “gateway” document invoking the appropriate ISO documents (currently over 300) wherever they apply. This allows any ISO documentation revisions to go through without changing the fundamental message. This approach has been accepted by a number of other national standard bodies, who will be issuing their own versions in due course. BS 8888 is written with more flexibility than the ISO documentation. Thus either of the dependency systems can be adopted, provided it is consistent. In the UK, BS8888 is now referenced by Def Stan 05-10 making it the preferred standard for military products. The "hard copy" version of BS 8888 has been revised every two years and is now available on disc. As from the 2007 revision, the definitive version is available online to subscribers. A number of other countries are adopting a similar approach, adapting BS8888 to the local situation and their own related standards. Thus the ongoing developments of the standard are likely to be echoed in these countries.

Two other UK standards have emerged from this work. "Design for manufacture, assembly, disassembly and end-of-life processing (MADE)", BS 8887:2006 draws on the specifications of BS 8888 to examine their production and disposal implications. This is intended for reference during the design stages. BS 8889, due for publication during 2008, will cover the quality control implications of BS 8888. This will indicate which measurements will be necessary to verify that the product does conform to the TPS documentation. These three standards will collectively cover "Technical Product Realization", TPR.

4 THE CHANGES

Basic engineering drawing, in terms of projection, line weights, sectioning etc. is unchanged. Some guidance has been relaxed to allow, for example, commas or points to be used for the decimal indicator, provided it is consistent and noted in the drawing data. 1st or 3rd angle projection may be used with the appropriate symbol to show which. The major changes are in the definitions of the tolerance requirements. A series of symbols are used to specify different types of tolerance. Six, cylindricity, flatness, profile of a line, profile of a surface, roundness (circularity) and straightness, are not related to a datum. Of those which are datum related, five are concerned with orientation (or attitude): angularity, parallelism, perpendicularity, profile of a line and profile of a surface. Six more are related to location: concentricity, coaxiality, profile of a line, profile of a surface, position and symmetry. The last two are related to run-out (also called composite): circular run-out and total run-out. Each of these is separately defined, but more than one may be applied to a feature. There are also a number of additional symbols, mainly letters, which modify the application of each form of tolerance. Between them they give all of the forms of tolerance necessary without the need for additional notes.

5 DESIGN EDUCATION & TRAINING IMPLICATIONS

In the UK, the BSI realized that training would be required to introduce these changes to practising engineers. Several training organizations could offer these courses, as could some of the larger industrial companies, but the BSI wanted to ensure that they were of an appropriate standard. They contacted several professional bodies and negotiated with the IED to provide an approval scheme. As this paper is being written, final approval of the training support and approval programme is in hand. The BSI will provide course material and arrange its own programme of courses. The IED will approve the course materials, accredit the training staff and the courses, and provide certificates for individuals completing the courses. This approval system will then be available for other training providers and in-house company courses, which meet the agreed standards. Once established, there is considerable scope for the materials to be translated for use in other countries and similar approval schemes established.

During the discussions of these training courses, it became clear that the interface between initial education and training, in all design disciplines, and professional practice would also need to adjust to the new system. We were aware that formal manufacturing drawing has been generally replaced by CAD tuition, now moving to solid modelling programs. While students can often manage the generation of a basic solid model, almost as if it were a computer game, the appreciation of the subtleties of drawings as a means of communicating with the manufacturer is often lost. Our discussions have led us to produce recommendations for the drawing related content of appropriate engineering degree and sub-degree courses as well as equivalent courses for product designers.

These recommendations are patterned on existing professional requirements with various levels of expertise of different aspects of drawing specified for different levels of the professions. These have been written in general terms to be applicable to all manufacturing industries and associated types of design activity. Since the BSI has no remit to set professional standards, it will be up to course providers and their various accreditation bodies to consider how to incorporate these recommendations as they see fit. The current proposal is that these recommendations will form an annex to BS8888.2008 due for publication in October. It would be hoped that if they are accepted by the UK professional bodies and course providers, they will then be considered for adoption by similar bodies in other countries conforming to the ISO approach.

REFERENCES

[1] Associated Press, Vatican City, reported in the Guardian, 7/12/07.

[2] De Re Metallica, Georgius Agriccola (Georg Bauer), 1556 – English translation by Hoover (later USA President) and Hoover, 1912.

[3] The Various and Ingenious Machines of Agostino Ramelli, 1588 – modern translation by M T Gnudi & E S Ferguson, 1976, Dover Press.

EurIng Colin LEDSOME
50 St Dunstans Road
Hanwell
London
W7 2HB
Colin.Ledsome@btinternet.com
+44 (0) 20 8840 3916