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Colin A. Ronan

Excerpt

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Engineers: their status, tools and materials

Mechanical engineering in China reached a very high stage of development at a time when Western engineering was still in a comparatively primitive state. Yet advanced though it became, it may be described as 'eotechnic', depending upon readily available naturally occurring materials. In its Chinese manifestation this meant primary reliance on wood, bamboo, stone and water. That is not to say that metals were unknown; indeed, they too were of great importance. From the Zhou [Chou] period (from the first millennium to the third century BC) when bronze was used for weapons, and in a refined form for gear wheels and crossbow-triggers in the Han (202 BC to AD 220), a time when cast-iron ploughshares were also in general use, and even steel-making was first practised, the Chinese used metals for what seemed to them appropriate purposes. In some respects, such as the mastery of iron-casting, and the first use and knowledge of zinc, the Chinese were much ahead of the Europeans. Yet it is true to say that most engineering constructions of any large size continued to be mainly of wood and stone. In this, change did not come until Western Renaissance technology spread over the Asian continent.

Yet if the Renaissance brought changes to East Asian technology, its practitioners were quite unaware of the origins of their subject. Hardly anyone in the Middle Ages would have noticed that technology had a history. Not until a literary quarrel in the sixteenth and seventeenth centuries AD, did it gradually dawn on historians that the ancient Romans did not write on paper, knew nothing of printed books, and used no collar harness, spectacles, explosive weapons or magnetic compasses. The disquiet caused by this realisation was partly the occasion of the controversy between the 'Ancients' and the 'Moderns', which took its place as an important aspect of the inevitable clash between the humanistic polymaths and the experimental philosophers. Among the protagonists of the Moderns, Jerome Cardan in 1550 signalled the compass, printing and gunpowder as the three inventions to which 'the whole of antiquity has nothing equal to show'. Almost a century later, in 1620, Francis Bacon in his *Novum Organum* was even more emphatic:

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It is well to observe the force and virtue and consequence of discoveries. These are to be seen nowhere more conspicuously than in those three which were unknown to the ancients, and of which the origin, though recent, is obscure and inglorious; namely, printing, gunpowder and the magnet. For these three have changed the whole face and state of things throughout the world, the first in literature, the second in warfare, the third in navigation; whence have followed innumerable changes; insomuch that no empire, no sect, no star, seems to have exerted greater power and influence in human affairs than these mechanical discoveries.

Bacon was mistaken in thinking that these inventions were inglorious, but few writers at that time, and few historians later, recognised clearly their non-European origin, or drew from the fact its full implications. As far as mechanical engineering is concerned, something of all this will become evident in what follows.

THE NAME AND CONCEPT OF ENGINEER

A few words may not be out of place here regarding the origins of the terms used for engineers in Western languages and in Chinese. To our minds the word 'engine' has come to have so vivid and precise a meaning that it is hard at first to remember that it derives from that quality of cleverness or ingenuity which is (or was thought to be) inborn in certain people – 'ingenium', indwelling genius, innerly generated. Since the derivatives of these roots were already in common Roman use for expressing qualities of wit, craft and skill, it is not surprising that 'ingeniarius', as a term in the more restricted sense, is found in Europe with increasing frequency from the twelfth century AD onwards. Not till the eighteenth was it freed from its primary military connotation. The course of events in China was not quite parallel to this.

From the earliest times the word *gong* [*kong*] (工) implied work as an artisan, but technical as opposed to agricultural. This is perpetuated in the modern term *gong cheng* [*kung chhêng*] (工程), the second of the two characters having originally meant measurement, dimension, quantity, rule, examination, reckoning, etc. Other old words such as *ji* [*chi*] (機) (originally the loom, the supreme machine) and *dian* [*tien*] (電) (originally lightning) came in due course to do duty for mechanical and electrical devices respectively. But none of their combinations, as applied to persons, is even medieval. The really old term for artisan-engineer is *jiang* [*chiang*] (匠 or 匠), which is probably a carpenter's square. One ancient oracle-bone form (𠄎) actually shows a man holding a carpenter's square *ju* (chü) (矩 or 矩). The word *gong* itself also derives from a drawing of this instrument. It is safe to conclude

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that in Chinese culture, primarily eotechnic as it was, engineering work *par excellence* was woodwork. The *Zhou Li* [*Chou li*] (Record of the Institutions of (the) Zhou [Chou] (Dynasty)) of Former Han times calls master-craftsmen *Guo Gong* [*Kuo Kung*] (國工) or Master Carpenters.

However, this is not the whole story. Technical ability which was particularly skilful and admirable was called *qiao* [*chhaio*] (巧). The radical character on the right here is interesting because it is related to a number of other forms of which the general meaning is 'that of breathing out'. Very familiar is the terminal expiatory word *xi* [*hsi*] (兮) used so much in Zhou and early Han poetry. Some relatives such as *hao* (兮 or 號), to call out, are still in common use. The significance of the meaning of the word for engineering genius in Chinese, therefore, would be identical with that of Latin, but expressed in the opposite way, not emphasising that genius which was born *in*, but that which was manifested and breathed *out*.

Sometimes artisans and engineers were simply called 'makers' or 'doers', the term 'Makers or Doers' being applied, for example, as early as Qin [Chhin] times (third century BC) to officials in charge of artisans and workshops. The associations of Chinese terms for engineers and artisans seem, therefore, always to have been more civilian and less military than those used in the West.

ARTISANS AND ENGINEERS IN FEUDAL BUREAUCRATIC SOCIETY

In volume 2 of this abridgement the point was made (pp. 76 ff) that astronomers were part of the civil service. To some extent, and on a lower plane, artisans and engineers also participated in this bureaucratic character, partly because in nearly all dynasties there were elaborate Imperial Workshops and Arsenals. An additional reason was that, during certain periods at least, those trades which possessed the most advanced techniques were 'nationalised', as in the Salt and Iron Authorities under the Former Han (that is from 119 BC onwards). Also, as we shall see, there was a tendency for technicians to gather round the figure of one or another prominent official who encouraged them as his personal followers.

We are, of course, not here dealing with philosophers, princes, astronomers or mathematicians, the educated part of the Chinese population, but with those concerned with the obscurer expanses of the trades and husbandries. Certainly they applied scientific principles, whether or not always fully formulated, but now a new factor enters. We can no longer leave out of account the mass of the workers and the conditions under which they laboured. They were the human material without which the planners of irrigation works or bridges, or vehicle workshops, or even the designers of astronomical appa-

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ratus, could have done nothing, and not seldom it was from them that ingenious inventors and capable engineers rose up to leave particular names in history.

It is generally allowed that the most important document for the study of ancient Chinese technology is the *Kao Gong Ji* [*Khao Kung Chi*] (Artificers' Record) chapter of the *Zhou Li* [*Chou Li*]. Though the book in general is a Han compilation, it embodies a great deal of earlier date, probably from an official compilation of the State of Qi [Chhi] in the Warring States period (480 to 221 BC). Indeed, careful study indicates that much of it dates from not later than the second century BC and refers to the early part of the third century BC, as well as to still earlier periods. We are therefore dealing with a time when the Great Wall of Qin Shi Huang Di [Chhin Shih Huang Ti] was under construction, and at a period in the West when Euclid was busy at the new Library and Museum at Alexandria, and one of the ancient 'Seven Wonders of the World' – the giant lighthouse on the island of Pharos in the harbour there – was being built.

Its opening paragraphs are so interesting that they must be quoted extensively:

The State has six classes of workers, and the hundred artisans form one of them.

There are those who sit to deliberate on the Dao [Tao] (of Society) and there are others who take action to carry it on. Some examine the curvature, the form and the quality (of natural objects) in order to prepare the five raw materials (presumably metal, jade, leather, wood and earth), and to distribute them for making instruments (useful for) the people. Others transport things rare and strange from the four corners (of the world) to make objects of value. Others again devote their strength to augment the products of the earth, or to (weave tissues from) silk and hemp.

Now it is the princes and lords who sit to deliberate upon the Dao, while carrying it into execution is the function of ministers and officials. Examining the raw materials and making the useful instruments is the work of the hundred artisans. Transportation is the affair of merchants and travellers, tilling the soil belongs to the farmers, and weaving is the office of women workers . . .

Tools and machines were invented by men of wit (*zhi zhe* [*chih chê*]), and their traditions maintained by men of skill (*qiao zhe* [*chhaio chê*]); those who continue them generation by generation are called artisans (*gong*, [*kung*]). So all that is done by the hundred artisans was originally the work of sages. Metal melted to make swords, clay hardened to make vessels, chariots for going on land

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and boats for crossing water – all these arts were the work of sages.

Now heaven has its seasons and earth has its *qi* [*chhi*] (local influences), particular stuffs have their virtues (*mei*) and particular workers have their skills; if these four things are brought together, something good comes out of it . . .

There now follow various examples, among them descriptions of excellent products from various regions, such as the knives of (the state of) Zheng (Chêng) and the double-edged swords from Wu and Yue [Yüeh]. Then, after remarks about the seasons, the text continues:

Generally speaking, wood-working comprises seven operations, metal-working six, treatment of skins and furs five, painting five and polishing five, modelling in clay two. Woodwork includes the making of wheels, chariot bodies, bows, pikestaves, house-building, cart-making, and cabinet-making with valuable woods. Metal-work includes forging (*zhu* [*chu*]), smelting (*ye* [*yeh*]), bell-founding, making measures, containers, agricultural implements and swords. Work with skins includes drying, making hide armour, drums, leather and furs. Painting includes embroidery in one or more colours, the dyeing of feathers, basketry and silk cleaning. Polishing includes the working of jade, the cutting and testing of arrows, sculpture and the making of stone-chimes. Modelling in clay includes the art of the potter and that of the tile-moulder.

This last was the art most esteemed by the dynasty of Shun. The Xia [Hsia] gave first place to the art of house-construction, and that of the Yin (Shang) preferred the art of making vessels. But that of the Zhou [Chou] set highest the work of chariot body builders.

The whole passage shows something of the characteristic Chinese love of arbitrary systematisation, but is clearly based on fact. Moreover, in the last paragraph, mention of the favourite techniques of several dynasties is an example of their correlative thinking – the connections they formulated between things formed of similar elements in the basic Five Element chain. (See this abridgement, volume 1, pp. 153 ff)

Again, the four conditions of industrial production – season, local factors, virtues of materials and skill – given in the fourth paragraph provide interesting statements about animal and plant ecology, as well as providing a background to the Chinese care in siting industries according to the presence locally of coal or metallic ores, forests, water and so on. Admittedly, the descriptions of type of artificer seem meagre, far less complete than the tables of officials with their ranks and classes of assistants in other ministries. But

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this is because those for the Ministry of Works were in a section of the text now lost. What we have are mentioned in Table 47 (below), and we do know that the Imperial Workshops certainly produced all ceremonial objects, commodities of daily life, as well as vehicles and machines, required for the courts of the emperor and the princes. What is more, there could be no sharp distinction between such work and the manufacture of arms and equipment for the imperial forces. And when the salt and iron industries were 'nationalised', all the artisans concerned in them must also have come under immediate government control.

Nevertheless, it is safe to assume that when any large or unusually complex piece of machinery was constructed (e.g. the early water-mills) this was done either in the Imperial Workshops or under the close supervision of important provincial officials. For all dynasties seem to have had Imperial Workshops, so in general one can conclude that a considerable proportion of the most advanced technologists in all ages in China were either directly employed by, or under the close supervision of, administrative authorities forming part of the central bureaucratic government.

Yet not all were employed in this way. The great majority of artisans and craftsmen must always have been connected with small-scale family workshop

Table 47. *Trades and industries described in the Kao Gong Ji chapter of the Zhou Li*

(A) WORKERS IN STONE AND JADE

Jade workers ^a	<i>yu ren</i>	玉人
Stone carvers	<i>diao ren</i>	雕人
Stone chime makers	<i>qing shi</i>	磬氏

(B) CERAMICS WORKERS

Potters	<i>tao ren</i>	陶人
Moulders (tiles)	<i>fang ren</i>	甃人

(C) WOOD WORKERS

Arrow makers	<i>jie ren</i>	柳人
Bow makers ^b	<i>shi ren</i>	矢人
Cabinet makers in valuable woods ^c	<i>gong ren</i>	弓人
Weapon handle makers	<i>xi ren</i>	梓人
Surveyors, builders and carpenters	<i>lu ren</i>	廛人
Agricultural implement handle makers, <i>see</i> Cartwrights	<i>jiang ren</i>	匠人

(D) CANAL AND IRRIGATION DITCH BUILDERS (and hydraulic engineers in general)

Hydraulic workers ^d	<i>jiang ren</i>	匠人
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(E) METAL WORKERS (<i>gong jin zhi gong</i>)		
'Lower alloy' founders ^e	<i>zhu shi</i>	蔡氏
'Higher alloy' founders ^f	<i>ye shi</i>	冶氏
Bell-founders	<i>fu shi</i>	晁氏
Measure makers	<i>li shi</i>	樂氏
Plough makers	<i>duan^g shi</i>	段氏
Sword-smiths	<i>tao shi</i>	桃氏
(F) VEHICLE MAKERS ^h		
Wheelwrights	<i>lun ren</i>	輪人
Master wheelwrights	<i>guo gong</i>	國工
Body makers	<i>yu ren</i>	輿人
Shaft and axle makers	<i>zhou ren</i>	辵人
	<i>zhu ren</i>	軸人
Cartwrights ⁱ	<i>che ren</i>	車人
(G) ARMOURERS (of hide, not metal)		
Cuirass makers	<i>han shi</i>	函氏
(H) TANNERS		
Tanners	<i>wei ren</i>	鞣人
Skinners	<i>bao ren</i>	鞣人
Furriers	<i>qui ren</i>	鞣革人
(I) DRUM-MAKERS		
	<i>yun ren</i>	鞞人
(J) TEXTILE, DYEING, AND EMBROIDERY WORKERS		
(<i>hua i chih shih</i> 畫織之事)		
Feather-dyers	<i>zhong shi</i>	洈氏
Basket-makers	<i>kuang ren</i>	筐人
Silk-cleaners ^j	<i>mang shi</i>	浬氏

^aMuch information about the forms of the various ceremonial pieces, but hardly a word about the techniques of working.

^bA long and elaborate section, which makes no mention of the crossbow.

^cMainly musical instruments and cups. They had a foreman or manager, *zi shi*.

^dThis section contains valuable information on irrigation canals, cf. *Science and Civilisation in China* volume IV part 3.

^e'Lower alloy' bronze was a 3 parts copper: 2 parts tin mixture, said here to be used for writing knives.

^f'Higher alloy' bronze was a 3 parts copper: 1 part tin mixture, said here to be used for arrow-heads, lance-heads, etc.

^hTheir measurements and dimensions are related to standard weapon lengths.

ⁱAlso make handles for agricultural implements.

^jThose who remove the gum from the natural silk.

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production and commerce. Indeed, the largest part was played by handicraft production independently undertaken by and for the ordinary people. As a result, particular localities derived fame from skills which tended to concentrate there, such as the lacquer-makers of Fuzhou [Fuchow], the potters of Jingdezhen [Ching-tê-chen], or the well-drillers Ziliujing [Tzu-liu-ching] in Sichuan [Szechuan]. Over and over again, people of the countries bordering China expressed their respect for the artisans of China. Nor did they hesitate to ask for them when circumstances permitted. Thus in 1126 AD, when nomadic tribes from Manchuria – the Jurchen (Jin [Chin]) Tartars – besieged the Song [Sung] capital at Kaifeng [Khaifêng], they demanded from the city all sorts of craftsmen, including goldsmiths and silversmiths, blacksmiths, weavers, tailors and even Daoist [Taoist] priests. Again, when the famous Daoist Qiu Changchun [Chhiu Chhang-Chhun] made his famous journey from Shandong [Shantung] to Samarkand at the request of Genghis Khan in 1221, he met Chinese workmen everywhere. In Outer Mongolia they came in a body to meet him, with banners and bouquets of flowers; when he got to Samarkand he found numbers more. And as late as 1675, we find a Russian diplomatic mission to Beijing [Peking] officially requesting that Chinese bridge-builders be sent to Russia.

Where did the Chinese inventors and engineers come from? They were commoners (*xiao min* [*hsiao min*]) (小民), and for the ancient philosophers 'menial men' (*xiao ren* [*hsiao jen*]) (小人) as opposed to 'magnanimous quasi-aristocratic scholarly official men' [*jun zi* [chün tzu]] (君子). Having surnames they were of the *bai xing* (*pai hsing*) (百姓) (the 'old hundred families'), and belonged to the *bian min* (*pian min*) (編民) (registered people). But whatever the extent of government-organised production from time to time, the State relied upon an inexhaustible supply of unpaid labour in the form of the *corvée* (*yao*, 徭 and 繇), (*yi* [i], or *yu* [yü], 役); (*gong yu* [*kung yü*], 公役). In Han times every male commoner between the ages of twenty (or twenty-three) and fifty-six was liable for one month of labour service a year, unless belonging to some specially exempted group. Technical workers certainly performed these obligations in the Imperial Workshops or in the factories of such enterprises as the Salt and Iron Authorities. These organisations were never staffed by slaves, and as time went on there naturally grew up the practice of paying dues in lieu of personal service so that a large body of artisans were 'permanently on the job'. In Yuan times (AD 1271–1368) government artisans were distinguished from military artisans, though both received pay and rations, differing from the private civilian artisans, the services of whom, however, could be requisitioned from time to time. Artisans were always spared by the Mongol (Yuan) conquerors, who assembled them in government factories. As in the Song [Sung], artisans could not be conscripted for any service other than their trade. During the Ming (AD 1368–1644), a rota of technical

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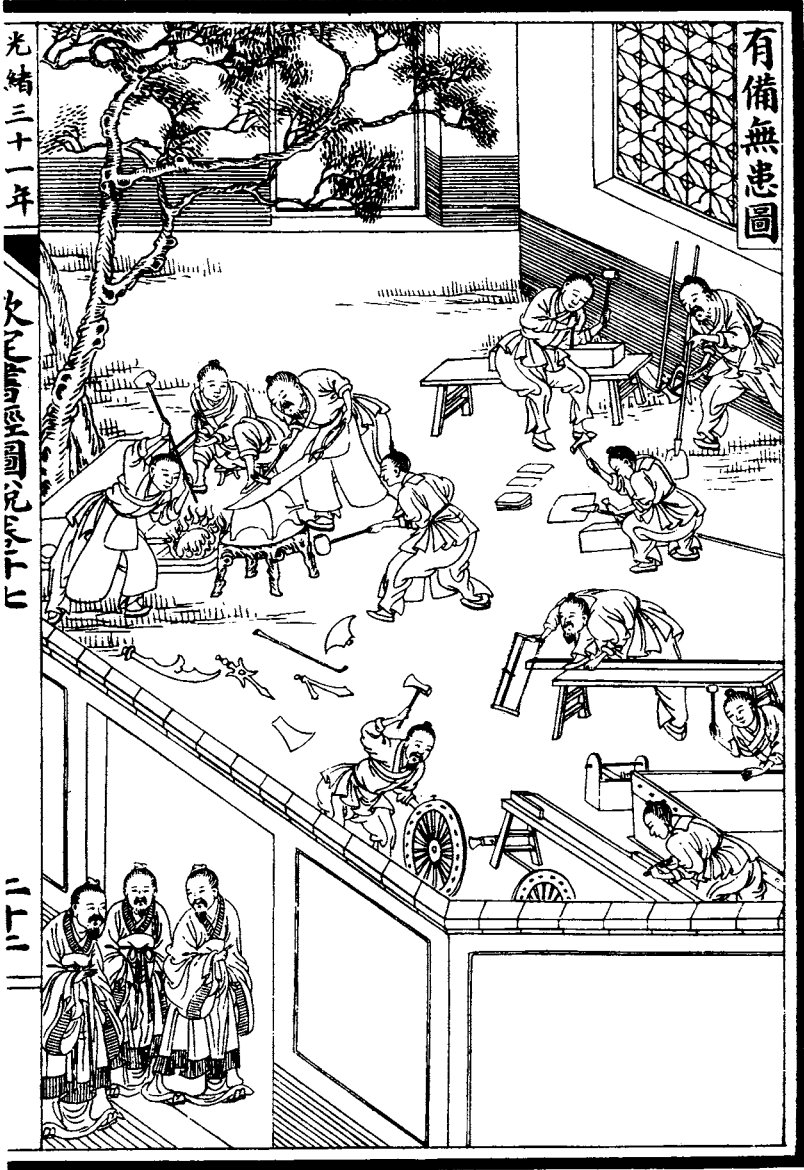


Fig. 247. A late Qing [Ching] representation of artisans at work in the Imperial Workshops. From the *Qinding Shu Jing Tu Shuo* [*Chhin-Ting Shu Ching Thu Shuo*] (*The Historical Classic with Illustrations*). Qing (edition by imperial order 1905).

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corvée labour in government factories according to regular registers became prominent.

Artisans who were regular commoners were by no means the lowest social level in ancient and medieval China. Below them came a number of 'depressed classes'. The general term for these was *jian min* [*chien min*] (贱民) 'base' or 'ignoble' people in contradistinction to the *liang ren* [*liang jen*] (良人), the 'commoners'. The ignoble were not slaves, though slavery did exist in ancient and medieval China; it was primarily domestic in character and originally essentially a punishment. As far as unfree artisans were concerned, their proportion was less than 10 per cent of the whole mass of workers in the crafts and techniques.

In the Han, like the Zhou [Chou] before it, male slaves were those condemned to penal servitude, female ones to grain-pounding. Though war captives sometimes suffered this fate, in ancient times the main source was certainly from criminals and their whole families. A great many were owned directly by the imperial State, but the line is hard to draw because State slaves were often given to high officials and nobles in reward for services or as presents. Their status, which they shared with no other groups, was that of property; but disabilities such as fixation of domicile, restrictions of marriage outside their own group, and restraint from change of occupation were also suffered by the 'ignoble' class. Indeed, the general idea of permanence of technical trade was a long-lasting one, but convicts whether men or women were 'enslaved' for a term of years, or for life, with no descendants. As in the ancient West they were sent to the mines.

We might well expect technicians among the slaves, the descendants of convicts, since special training and long experience would be more natural among people spending a lifetime in servitude, and indeed it seems likely that the life of a government slave tradesman was often considerably more comfortable, and certainly more secure, than that of a 'free' yeoman artisan.

As to the skills possessed by slaves, a remarkable document from 59 BC, purporting to be a purchase contract, has survived since the Han. Apart from a slave's labour in garden and orchard, he was supposed to plait straw sandals, hew out cart shafts, make various pieces of furniture and wooden clogs, whittle bamboo writing tablets, twist rope and weave mats – but besides all this he was to make knives and bows for sale in the neighbouring market. Thus it appears that among the slaves there were always those who were skilled craftsmen, though never as many as among the commoners who had to act as *corvée* labour.

The Chinese also used the term *tong* [*thung*] (童 和 童), which may perhaps best be translated as "serving-lads". As this term had a strong industrial undertone, one is almost tempted to view them as bonded apprentices, perhaps for a long term of 'educational' years. Indeed, in the third and second centuries