CURRENT WORK ON THE ANTIKYTHERA MECHANISM

MICHAEL T. WRIGHT *CURATOR OF MECHANICAL ENGINEERING, THE SCIENCE MUSEUM OF LONDON*
ALAN G. BROMLEY *PROFESSOR, BASSER DEPARTMENT OF COMPUTER SCIENCE, UNIVERSITY OF SYDNEY*

Our research, aimed at gaining a clearer understanding of the detailed arrangement of the Antikythera Mechanism, remains in progress. We have few firm conclusions to offer, but we believe that the peculiar interest attaching to the Mechanism is such that our report may reasonably claim attention.

The Antikythera Mechanism, recovered from a shipwreck discovered off the island of Antikythera in 1900, is preserved in the National Archaeological Museum in Athens. It is datable to the first century B.C., making it by far the oldest intricate mechanical device known.[1,2]

As recovered, the surface of the instrument was obscured by corrosion products and marine accretions. Later, painstaking mechanical cleaning of an extraordinarily delicacy by the museum's own staff revealed extensive evidence of mechanical details and inscriptions.

The Mechanism as we now have it comprises five main fragments of significant size, **A, B, Γ, Δ** and **E,** and a quantity of detached flakes.[3] The most remarkable feature, at least of **A,** the largest and thickest fragment, is the evidence that it contained a number of toothed wheels; a number are seen on the surface, and with the aid of radiography one may make out the traces of over thirty. Thus the Antikythera Mechanism is not only far the earliest surviving geared mechanism; it is also remarkably complex. It is clear that it was the outcome of accomplished design and skilful manufacture.

The first account of the Mechanism to reflect the great intricacy of its internal arrangement, and to attempt a plausible reconstruction, was that published by Professor Derek Price in 1974. This achievement was made possible by the superb radiographic examination that had been carried out by Dr. Charalambos Karakalos. Price's work was a remarkable synthesis, complementing the new evidence of radiography with a wide knowledge of the literature and a long experience of other mechanical devices.[4]

Price proposed a reconstruction of the major elements of the mechanism, taking account both of the mechanical arrangement and of the inscriptions, according to which it was a calendrical device, displaying the positions of the Sun and the Moon in the Zodiac and incorporating in the dial display a calendar of the months to be read by the indicator for the Sun's position. The opposite face of the instrument carried other displays which were less clearly defined, but the internal mechanism itself suggested that some part of it should be devoted to displaying the events of the synodic month, the Moon's age or a representation of its phases.

At the heart of Price's reconstruction are two major mechanical features. The first, and more surprising one, is a differential mechanism. There are three connections to any such assembly, and in this case two are seen to be interconnected by the other feature, a train of wheels of which the velocity ratio seems to be the Metonic ratio, which expresses the relationship between the length of the year and the length of the month in the form: 19 years = 254 sidereal months.

The function of a differential mechanism, when fed in this way with two motions, is to yield an output related to the difference, or sum (depending on the relative directions of rotation), of the two input motions. In this case, the difference was taken of the two input motions, in the velocity ratio 19:254, giving an output relating to the synodic month, that is, the phases of the Moon. Thus, in 19 years there are 254 sidereal months or 254-19 = 235 synodic months.

The largest fragment, **A**, contains nearly all the gear wheels, mounted on a plate that forms the frame of the mechanism; it also includes part of an inscribed dial plate parallel to the frame plate. Fragment **B** may be fitted to that side of fragment **A** and includes another part of the same dial.

Although there is no fit between fragment **Γ (C)** and the others, it includes a fragment of dial marked out with the Zodiacal constellations and the months of the year. Price argued that this was the dial on which the positions of the Sun and Moon in the Zodiac were displayed, their indicators making one revolution in one year and in one sidereal month respectively.

The remains of further gearing, and the complexity of the other dial structure, indicate that there must have been other display functions, which could not be fully determined. But the general nature of the Mechanism as an astronomical and calendrical device was confirmed by what could be deciphered of the inscriptions.

In order to place the Mechanism in a context, Price appealed to the evidence of literary references from the third century B.C. onwards, referring to gearing and to mechanical representations of astronomical phenomena. The evidence is slender indeed, and the Mechanism is much more complicated than those references alone would lead one to suspect, but Price argued for a continuing tradition through the early Hellenistic period, later transmitted from Hellenistic into Islamic culture and thence still later to the Latin West, perhaps culminating in the invention of clockwork.

Price's thesis is strengthened by the appearance in 1983 of the London Sundial-Calendar, another astronomical-calendrical geared mechanism from the Hellenistic world.[5] Although it is from 600 years later, and is far simpler, it is the closest comparison material that we have for the Antikythera Mechanism. At the same time, by comparison with the "Box of the Moon" described by al-Biruni some 500 years later still, it provides artefactual evidence for the transmission of mechanical technology from Hellenistic to Islamic culture.[6]

The appearance of the Sundial-Calendar drew our attention back to Price's paper, and doubts over Price's treatment were the starting point for our present work on the Antikythera Mechanism. The architecture of Price's treatment is remarkable, but it appeared that, due to its exceptional importance, the Mechanism merited a greater attention to detail.

There are features in Price's reconstruction which appear unsatisfactory, most obviously the way in which it was to be driven by turning a slow-moving mobile.[7] Modifications to this and some other details were embodied in a new reconstruction based in all other respects on Price's data.[8] The demonstration model built to this design proved to be a useful aid in studying the design problems of the device and in describing our concerns to others, although subsequent study of the original fragments has thrown into doubt several of the assumptions built into that reconstruction.

Further progress has depended on access to the original fragments, a privilege for which we are deeply grateful to the Greek authorities.

Our first campaign was one of close visual inspection, note-taking, measurement and photography. Apart from making a complete photographic record, we took photographs in stereographic pairs with controlled geometry; these have proved invaluable in allowing us to continue our investigation and discussion between visits to the museum. A simple instrument for coordinate measurement was devised, with which the positions in three dimensions of all appreciable surface features were recorded, to 0.1 mm. in each direction, for future reference.

From the outset it was clear that the visible details were not altogether as described by Price. In particular, there are many significant features that Price did not report, and some that actually conflict with Price's interpretation. Thus, for example, there are pillars rising from the large wheel visible on the face of **A**, and we can trace the positions of others in a roughly symmetrical pattern; it is clear that the wheel carried on it a structure that stood above the upper edge of the contrate wheel that stands on edge to one side of the large wheel and in mesh with it.[9] Therefore Price's arrangement, in which the contrate wheel serves as a reversing gear giving motion to another similar large wheel lying above the existing one, must be abandoned. Moreover, the structure at the centre of the large wheel is remarkably complex, with perhaps three concentric arbors of which the pipe supporting the large wheel is the outermost.

We are led to suppose that within the lost structure mounted on the large wheel there must have been further gearing taking motion from one or both of the inner arbors. This lost epicyclic gearing implies in turn an elaboration of the display seen on the dial.

Other observations also indicate that the mechanism must have been more complex than Price indicates. As a corollary, the surviving fragments comprise a smaller fraction of the whole than Price's reconstruction implies. Unfortunately, it follows further from this that the probability of devising a wholly satisfactory reconstruction is low.

We met Dr. Karakalos, whose radiographic work had been the key to Price's progress, and discussed radiography of the Mechanism with him. Karakalos's work left nothing to be desired in quality, but it appeared that a further campaign of radiographic examination might be helpful.

Our application of the radiographic technique "linear tomography" has already been described, along with some of the first results that we achieved.[10] In this we employ apparatus designed and made by ourselves in combination with a conventional industrial X-ray source. Plates are obtained on which only features of the object in one closely-defined plane, which may be chosen at will, yield sharp images, and sets of such plates are exposed to represent a series of parallel cross-sections through the object. In general we found sequences of exposures resolving planes separated by 0.5 mm. sufficient. In some instances we made sequences with the planes separated by 0.25 mm. By the careful comparison of adjacent exposures in these sequences it is possible to resolve the position of many features to the nearest plane.

With this simple arrangement we have already obtained some very revealing results, but one of the features of the technique is that one ends the campaign with a great bulk of material requiring careful subsequent analysis, and this work continues.

We have also made a number of plain radiographs in stereographic pairs, using the tomography apparatus to control the geometry. These are useful in providing at a single view an impression of the arrangement of features in depth which one can build up only gradually from the tomograms, but they are less easy to use than stereographic photographs.

Tomography has revealed some new and unsuspected features, such as the one in fragment **Γ**, **(C)**, which we took as a case study in the previous paper. In this case, however, subsequent radiography has confirmed that the toothed feature is not a rack as we then suggested but the remnant of a hitherto unnoticed small contrate wheel. This serves us as a caution as to the care with which the results of tomographic analysis must be interpreted. Even with a clearer idea of the feature, we have still not yet made any sense of its mechanical arrangement; whatever its intended function it constitutes further evidence that the design was more complicated than Price's reconstruction suggests.

Another series provides images of the wheelwork at the very centre of fragment **A**. Here, according to Price, the motions related according to the Metonic ratio, representing the movement of Sun and Moon in the Zodiac, are connected to the differential gear. It had become clear from plain radiographs that the positions of three axes were such that the mutual engagements of the wheels on them was far more equivocal than Price's line drawing shows. These wheels cannot be seen directly at all, and it is impossible to judge their depths within the mass using plain radiographs alone.

The first indications of the tomography are disturbing; the wheels appear to be arranged not as the reconstruction requires but so that the direction of rotation of one of the connections to the differential gear is reversed. The results of such a modification to the scheme would be profound, since the differential gear would then yield an output related to the sum, not the difference of the motions of Sun and Moon, a function having no significance whatever. Such a change would force us to reappraise the whole

The Antikythera Mechanism : fragment A (80% reduced).
Phot. by A.G.Bromley & M.T. Wright.

The Antikythera Mechanism : fragment A (80% reduced).
Positive printed from radiograph by M.T. Wright & A.G.Bromley.

basis of Price's reconstruction. Amongst the trains of thought that present themselves, we must consider the possibilities that the fragment has become distorted so as to shift the rims of one or more wheels in depth, thus making a false engagement, or that the maker of the instrument was confused and that the design was garbled, or, especially in view of the reinterpretation of tomographic evidence mentioned above, that our present reading of the evidence is mistaken.

These instances serve as samples of the very considerable volume of new information that we have amassed. Much of it adds detail to Price's account; many features confirm that the instrument must have been more elaborate than earlier descriptions suggest; and some appear át present to be incompatible with Price's reconstruction or any reasonable variant of it. The analysis of this material is necessarily slow and difficult.

In conclusion we wish to record our warm appreciation of the kind cooperation and friendly support of the Director and staff of the National Archaeological Museum, in particular the former Curator of Bronzes Dr. Calligas and his successor Mrs. Proskinitopoulou and their conservation staff, and the head of the Chemistry Laboratory Mrs. Magou and her staff.

NOTES

1. The earliest formal account of the material from the Antikythera Wreck is to be found in: Σβορώνος, Ι.Ν., *Το εν Αθήναις Εθνικόν Μουσείον*, Athens 1903. A German edition was also published: Svoronos, J.N., *Das Athener Nationalmuseum*, Athens 1908.
2. A clear and concise account of the finding of the wreck, of all significant published work, to his date of writing, on the wreck and the artefacts recovered from it, and of earlier study of the Mechanism, is to be found in the introductory chapters of: Price, D.J. de S., «Gears from the Greeks», *Transactions of the American Philosophical Society*, new series, vol. 64 pt.7, 1974. The paper was subsequently published as an independent monograph as *Gears from the Greeks*, Science History Publications, New York 1975. It has been translated into Greek by Economou, N.A., under the title: *Γρανάζια από τους Έλληνες*, T.M.Th. Publications, Thessaloniki 1995.
   However, Price omits reference to the original Greek edition of Svoronos; see note 3.
3. The first four were noticed by Svoronos (note 3) and were so called by him; Price and other writers in languages other than Greek refer to them as A, B, C, and D respectively. Fragment E was found recently in the museum store by Dr. Calligas, then curator of bronzes. It is certain that it belongs to the mechanism; it fits positively between fragments A and B.
4 What follows is summarized from Price, op. cit., note 4.
5. Field, J.V. - Wright, M.T., «Gears from the Byzantines: a Portable Sundial with Calendrical Gearing», *Annals of Science*, 42, 1985, 87-138; also reprinted in: Field, J.V. - Hill, D.R. - Wright, M.T., *Byzantine and Arabic Mathematical Gearing*, Science Museum, London 1985;
   Field, J.V. - Wright, M.T., *Early Gearing*, Science Museum, London 1985, and also available in Greek as: *Πρώιμα Γρανάζια*, T.M.Th. Publications, Thessaloniki 1997;
   Wright, M.T., «Rational and Irrational Reconstruction: the London Sundial-Calendar and the early history of geared mechanisms», *History of Technology*, 12, 1990, 65-102;
   Field, J.V., «Some Roman and Byzantine Portable Sundials and the London Sundial-Calendar», *History of Technology*, 12, 1990, 103-135.
6. Hill, D.R., «Al-Biruni's Mechanical Calendar», *Annals of Science*, 42, 1985, 139-163; also reprinted in: Field, J.V. - Hill, D.R. - Wright, M.T., *Byzantine and Arabic Mathematical Gearing*, Science Museum, London 1985.
7. Zeeman, E.C., «Gears from the Greeks», *Proceedings of the Royal Institution of Great Britain*, vol. 58, 1986, pp.139-156.
8. Bromley, A.G., «Notes on the Antikythera Mechanism», *Centaurus*, vol. 29, 1986, pp.5-27;

Bromley, A.G., «Observations of the Antikythera Mechanism», *Antiquarian Horology*, vol. 18, 1990, no.6, pp. 641-652;
Bromley, A.G., «The Antikythera Mechanism», *Horological Journal*, vol.132, 1990, no.12, pp. 412-415 and vol.133, 1990, no.1, pp. 28-31.
9. In the nomenclature devised by Price, the contrate wheel is A and the large wheel B1.
10. Wright, M.T. - Bromley, A.G. - Magou, H., «Simple X-ray Tomography and the Antikythera Mechanism», *PACT* 45, 1992, VIII.3, 531-543.

ΠΕΡΙΛΗΨΗ

ΠΡΟΣΦΑΤΗ ΕΡΓΑΣΙΑ ΠΕΡΙ ΤΟΥ ΜΗΧΑΝΙΣΜΟΥ ΤΩΝ ΑΝΤΙΚΥΘΗΡΩΝ

M. T. WRIGHT - A. G. BROMLEY

Ο Μηχανισμός των Αντικυθήρων, στο Εθνικό Αρχαιολογικό Μουσείο Αθηνών, χρονολογείται στον πρώτο αιώνα π.Χ. και είναι ο παλαιότερος μηχανισμός με οδοντωτούς τροχούς στον κόσμο. Είναι πολύπλοκος, σύνθετος και αποσπασματικός.

Η μέχρι τούδε κατανόηση του Μηχανισμού βασίζεται στην εργασία του Καθηγητή Derek Price, ο οποίος τον περιέγραψε και κατέθεσε μια αναπαράσταση βασισμένη στις δικές του παρατηρήσεις. Επίσης, συζήτησε τη σημασία του εντάσσοντάς το στο γενικότερο πλαίσιο της πρώιμης ιστορίας των μηχανισμών με οδοντωτούς τροχούς.

Η αξιολόγηση του Price ως προς τη μεγάλη ιστορική του σημασία δεν αμφισβητείται και η ταύτιση της λειτουργίας του ως ημερολογιακής ή αστρονομικής εφεύρεσης φαίνεται ορθή. Όμως, η λεπτομερειακή περιγραφή του οργάνου επιδέχεται βελτίωση, οπότε και η αναπαράστασή του τίθεται σε αμφισβήτηση.

Περιγράφουμε τις προσεγγίσεις που υιοθετήσαμε στην πρόσφατη εργασία μας, στη μελέτη του Μηχανισμού με οπτική εξέταση και άμεση μέτρηση, απλή και στερεογραφική φωτογραφία, ακτινογραφία και γραμμική τομογραφία.

Δείχνουμε με ποιόν τρόπο οι παρατηρήσεις μας οδηγούν στην άποψη ότι ο Μηχανισμός ήταν πολύ πιο πολύπλοκος απ'ό,τι υποστήριξε ο Price. Επίσης, δείχνουμε πόσο πολύ η συσσώρευση περισσοτέρων πληροφοριών παραδόξως δυσκόλεψε, προς το παρόν τουλάχιστον, την περιγραφή της πιθανής διάταξης του οργάνου και του τρόπου με τον οποίο είχε ίσως σχεδιαστεί να λειτουργήσει. Κλείνουμε δίνοντας το γενικό πλαίσιο μερικών απο τα πρώτα αποτελέσματα, τα οποία προέκυψαν απο την ανάλυση των τομογραφικών εικόνων, την οποία εκπονήσαμε.