Early Precision Compound Machine from Ancient China

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The intricate carved decorations on the best jades from ancient China (*1*) are thought to have been made largely by hand and through the use of simple machines (*2*). Here I present evidence that the curved spiral grooves carved on a class of ornamental jade burial rings from the Spring and Autumn period (771 to 475 B.C.) appear to have a mechanical origin that involves a precision compound machine.

The oldest known excavated ring of this class with a secure provenance is M1:7 (Fig. 1A) from the tomb of a Chu minister (d. 552 B.C.) in Henan Xichuan Xiasi (*1*, *3*, *4*). Its 10 grooves are well described by Archimedes' (287 to 212 B.C.) spirals (*5*, *6*) of the form $r = \alpha*\theta$ (in polar coordinates, radius r, angle θ, and constant α). A transformation of a photograph of the ring from Cartesian (x, y) to polar (r, θ) coordinates (Fig. 1B) maps these spirals to lines with slope α. For the 10 spirals, I found that α is 6.51 ± 0.10 mm per radian (the mean ± SD of 10 best-fit lines). All of the spirals share a common origin (i.e., $r = 0$) that coincides with the geometrical center of the ring, and each carved groove conforms to the bestfit spiral curve within 200 μm (Fig. 1A).

Other Spring and Autumn rings with precise spiral grooves include excavated examples M102:1 and M102:2, from the tomb of the Marquis of Cai (d. 491 B.C.) at Anhui Shouxian (*3*, *7*); J2:31, from a hoard at Jiangsu Wuxian (*1*, *8*); a ring from Shaanxi Xian Shahutuo (*9*); and well-attested, published pieces in Western collections (*2*, *10*) (figs. S1 to S7). The uniformity and precision of these grooves strongly suggest a mechanical origin, contrasting the changing curvature, direction, and width of the carved strokes typical of contemporaneous intricate jade decoration. In order to produce the observed Archimedes' spirals, the device used to draft or directly carve these grooves must have had precisely linked rotational and linear motion. One possible reconstruction using technology known to have existed in 550 B.C. is shown in Fig. 1C. Although a simpler device, such as a string tethered to a spool, will trace out a spiral when unwound under tension, the spirals it generates are of a different mathematical form that does not match the real carved grooves.

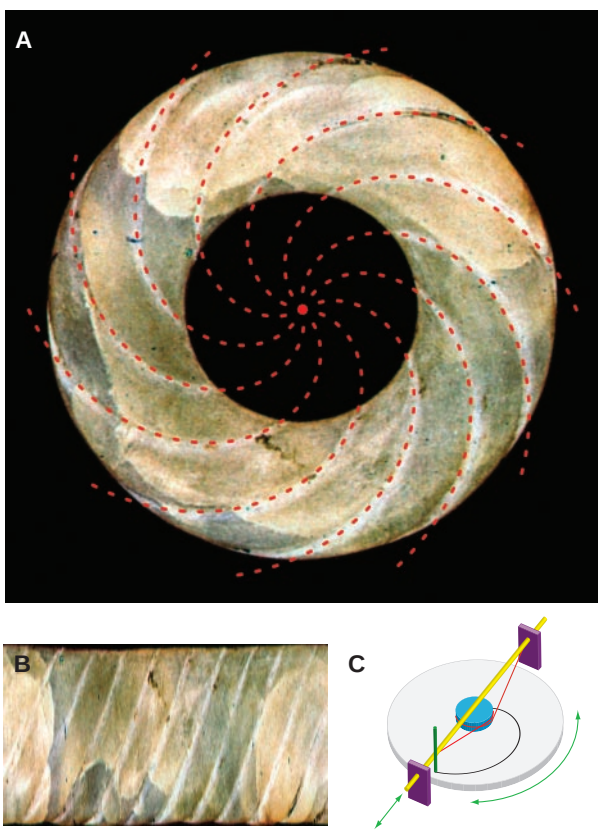

Fig. 1. (**A**) Jade ring M1:7 from Tomb 1 of the Chu minister at Henan Xichuan Xiasi (552 B.C.); diameter, 27 mm (*1*). The red dotted (theoretical) Archimedean spiral curves are all of the same equation and share the same center, differing only in rotation. (**B**) Image of ring M1:7 after transformation from Cartesian to polar coordinates, where the Archimedes' spirals are mapped onto lines with slope α. Away from the edges, where the three-dimensional relief of the ring distorts the spirals slightly, the grooves are all linear and parallel. (**C**) Schematic of one simple device to draft Archimedes' spirals. A string (red), tightly wrapped around the axle (blue) of the turntable (gray), has its ends fixed to a rod (yellow). Constraints (purple) on the rod force the stylus (green) to move radially. A constant linear displacement of the rod will rotate the turntable by a constant amount, generating the Archimedes' spirals (black).

Simple machines using only one form of motion, such as a potter's wheel, were in use well before the Spring and Autumn period; by contrast, the first historical references to compound machines precisely interconverting different forms of motion do not occur until writings attributed to Hero of Alexandria (c. 1st century A.D.) and possibly Plutarch's (45 to 125 A.D.) account of Archimedes (*11*). The Xiasi jade ring thus gives physical evidence for such machines at least three centuries earlier, implying greater mechanical sophistication than has previously been assumed for ancient China's Spring and Autumn period. The complex machine that created these spiral jade grooves may also be among the ancestors of the crank in China, inferred from Han dynasty (206 B.C. to 220 A.D.) sculptures to have mechanized a variety of agricultural processes such as milling and winnowing (*12*, *13*).

References and Notes

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Supporting Online Material
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Figs. S1 to S7
Table S1

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