ENIGMA: ACTIONS INVOLVED IN THE 'DOUBLE STEPPING' OF THE MIDDLE ROTOR.

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ABSTRACT: A description is given of the sequence of mechanical events which lead to the 'double stepping' of the middle rotor of the three-rotor Enigma. The sequence is also presented in tabular form.

INTRODUCTION

The 'double stepping' of the middle rotor of the three-rotor Enigma is a well-known phenomenon and has been written about in numerous technical publications in which Enigma is the focus of discussion. However, I have yet to encounter a detailed description of the internal machine actions involved. Perhaps this small contribution will fill that gap.

CONVENTIONS USED

In this description of the Enigma rotor movement sequence the following conventions have been adopted. The three rotors[1] are numbered from right to left as seen from the machine operator's viewpoint - thus, the 'fast' or right hand rotor is Rotor 1, Rotor 2 is in the middle position and the 'slow' or left hand rotor is Rotor 3. The associated ratchets, stepping levers and notches are similarly designated. e.g. Ratchet 3 is attached to Rotor 3, the primary function of Lever 1 is to move Rotor 1; Notch 2 is on the index ring of Rotor 2; ...and so on. Following this same convention, "left" and "right" in the body of the article are as seen from the viewpoint of the Enigma keyboard operator.

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[1] Four-rotor Enigmas, since the additional rotor does not step with keyboard inputs, have only three stepping levers. The stepping sequence is identical

ROTOR STEPPING

Enigma rotor-stepping is achieved via a lever (pawl) and ratchet mechanism. Each rotor incorporates, on its right hand side, a twenty-six position ratchet. There are three spring-loaded stepping levers, one for each movable rotor. The task of each is to engage the corresponding ratchet and move it forward. Levers 2 and 3 are identical in size and shape but Lever 1 has only about half the width of the other two. The reason for this difference will, I hope, become evident.

The narrow Lever 1 is located directly behind Ratchet 1 and is free to engage it. The contact surface of the wider Lever 2 sits astride the gap between Rotor 1 and Rotor 2, its right hand edge riding on a narrow shoulder machined on the left edge of Rotor 1's index ring. It is thus prevented from engaging its 'own' ratchet, Ratchet 2, which is aligned with the stepping lever's left hand edge. Lever 3, lying in a similar position between Rotor 2 and Rotor 3, rides with its right hand edge upon the index ring of Rotor 2 and is prevented from engaging Ratchet 3, with which its left hand edge is aligned.

When a key is pressed on the Enigma keyboard all three stepping levers move. Lever 1 engages Ratchet 1 and Rotor 1 moves accordingly. The other two rotors do not move because their respective stepping levers, though moving, are unable to engage the ratchets.

Once[2] during each complete revolution of Rotor 1, its index ring reaches a notch in the narrow shoulder upon which Lever 2 rides. Lever 2, being spring-loaded, drops into this notch and is thus in a position to engage the ratchet on Rotor 2 when the next key is depressed on the Enigma keyboard. With this input Rotor 2 moves forward, activated by Lever 2: Rotor 1 moves with it, activated simultaneously by both Lever 1/Ratchet 1 and by Lever 2/Notch 1. As Rotor 1 moves, the notch on its index ring also moves and Lever 2 is once again pushed back into a position from which it is unable to engage Ratchet 2. Note that this operation could be considered a 'double stepping' of Rotor 1 but, since Rotor 1 moves anyway in the normal course of events, activated by its own stepping lever and ratchet, the movement is unremarkable!

Similarly, once during each complete rotation of Rotor 2 its index ring is so positioned that Lever 3, its right-hand edge riding on the shoulder, drops into Notch 2; a position from which its left-hand edge can engage Ratchet 3 upon the next keyboard input. As the keystroke is made Lever 3 engages Ratchet 3 and Rotor 3 steps. Since Lever 3 is still engaged with the notch of Rotor 2 the movement of the stepping lever causes Rotor 2 to move also. The result is the 'double stepping' of Rotor 2. Rotor 1 is, as usual, moved by a Lever 1/Ratchet 1 combination.

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[2] Later in World War II, rotors with two notches were used by the German Navy. The principle remains unchanged except for the more frequent stepping.

Table 1 shows the actions involved in the stepping of a three-rotor Enigma machine. It is a modification of the table to be found in Deavours and Kruh [1, p.101]

Observed rotor Movement*			Actions causing rotor movement		
1	2	3	1	2	3
A	D	O			p3/r3
A	D	P			p3/r3
A	D	Q			p3/r3
A	E	R		p2/r2	p3/r3 and p2/n3
B	F	S	p1/r1	p1/n2	p3/r3
B	F	T			p3/r3
B	F	U			p3/r3

Table 1. Double stepping sequence of 3-rotor Enigma

Notes on Table 1:
p1, p2 and p3 are Levers 1, 2, and 3; respectively.
'p', for "pawl", is used to avoid confusion between the figure '1' and lower-case 'l'.

r1, r2 and r3 are the ratchets on Rotors 1, 2, and 3; respectively.

n2 and n3 are the notches on the index rings of Rotors 2 and 3; respectively.

*For those wishing to reproduce this sequence on an Enigma machine or with simulation software, the three Enigma Rotors which will give the above result are Rotor III in the 'slow' position; Rotor II in the middle and Rotor I in the 'fast' position.

REFERENCES

1. Deavours, Cipher A. and Louis Kruh. 1985. *Machine Cryptography and Modern Cryptanalysis. Norwood MA: Artech House*

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BIOGRAPHICAL SKETCH

David Hamer was educated, in England and the United States, as a physical chemist and mathematician; but spent the major part of his career in aviation. He has now (more or less) retired and has resumed his interest in things mathematical. These include classical cryptology, Enigma, modern data security methods, mathematical games and trying to win the New Jersey Lottery!