Enigma G: The Counter Enigma

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Abstract The history of Enigma G, the counter Enigma, is presented and traced from the very beginning of the development of the small, glow-lamp Enigma machine in early 1923 until the end of the Second World War. The commercial customers and governmental users of the machines are introduced and covered in considerable detail. The Hungarian machine, G 110, recently found buried in Poland, and its subsequent conservation by the Bletchley Park Trust, is then analysed and explained.

Keywords *Abwehr*, *Abwehr* Enigma, Bletchley Park (BP), Counter Enigma, *Deutsches Stickstoff-Syndikat*, Dutch Navy, Enigma, Enigma G, G31, G 110, G 312, German Armistice Commission, Hungarian Army, *I.G. Farben*, KK-machine, *Zählwerksmaschine*

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Introduction

Enigma G, also called Enigma G31, was normally referred to as *Die Zählwerksmaschine*, the counter Enigma, by the Germans, however, after the war this special version of the Enigma was often called the *Abwehr* Enigma. It is understandable that it was so-called, because most of the messages enciphered on this machine during the war were traffic from the German military intelligence service, the *Abwehr*. Nevertheless, that name is a misnomer, because even if the *Abwehr* was perhaps the biggest user of the machine, it was neither the first nor the only user. Enigma G was the final development in a series of Enigma machines equipped with a counter and where the rotors could be moved either backwards or forwards in synchronism (i.e., while maintaining their proper stepping and relative positions) to allow for the correction of errors. The idea for a commercial machine equipped with a counter was born as early as 1926. The new *Zählwerksmaschine,* or as the Germans expressed it: "*Glühlampen-Chiffriermaschine mit Zählwerk und zwangsläufiger Walzen-Kupplung*" — Glow-lamp cipher machine with counter and driven rotor coupling, went through at least three major design revisions before the Enigma G was finally launched in 1931. (Chiffriermaschinen AG 1928)

The Enigma G was produced in relatively small numbers. The estimate today is that less than 350 machines were produced. Compared with the large number of plugboard Enigma machines produced for the German army and navy, it is perhaps even strange that Enigma G is publicly known at all. However, Enigma G received its share of fame because it was the machine used by the 'sinister' *Abwehr* and whose communications Bletchley Park (BP) unravelled thanks, first of all to the eccentric codebreaker Dillwyn "Dilly" Knox, but also to his brilliant staff, Mavis Batey (née Lever) and Margaret Rock. The intelligence obtained through breaking the *Abwehr* ciphers, both machine and hand, played an important part in the double-cross system of rounding up and turning the *Abwehr's* agents in Britain and keeping a watchful eye on their agents' activities in Spain and Portugal. And then suddenly the machine became front-page news on 1 April 2000, when the Bletchley Park Trust's then sole example of the Enigma G machine, G 312, was stolen. The puzzling theft was a cavalcade that ran over several months until the machine suddenly turned up in a parcel addressed to the BBC television presenter Jeremy Paxman on 17 October 2000, and it has never really been solved. That it was much more than an April-fool's joke gone bad is nevertheless clear, however, it rekindled people's interest in the Enigma and made many curious to know more. Seen in this light, and also due to the positive outcome when the machine was returned, the theft was not altogether a negative affair.

Figure 1. Enigma G 312, the machine stolen from the Bletchley Park Trust (BPT) in April 2000. Photo © 2019 courtesy of BPT.

In the remainder of this article the authors will look beyond the headlines and stories about the *Abwehr* Enigma and try to give a better understanding of Enigma G and its development from a mere idea to an operational machine. Furthermore, we will try to follow the history of one of the earliest Enigma G machines, G 110, which was sold to the Hungarians in 1931. This machine, an archaeological relic that has now

been restored by the Bletchley Park Trust and added to their cryptological collection, shows what most likely happened to thousands of Enigma machines in the final days of the Second World War.

The First Glow-Lamp Machines

The first idea for a less complex cipher machine using glow lamps instead of a printer seems to have come early in 1923. Until then the Enigma cipher machine made by *Gewerkschaft Securitas*, Berlin, as the Enigma company was then called, had been a big and heavy machine equipped with a printer. A blueprint dated 31 May 1923, shows the electrical and mechanical principles of a new machine with glow lamps and perhaps more astonishingly a reflector or as the Germans called it, an *Umkehrwalze* or UKW.[1] All the Enigma machines until then had been straight through machines where the cleartext characters entered on one side of a bank of electrical rotors or wired wheels[2] and the ciphertext characters exited at the other side. The system was not symmetrical such that to decipher a message the keyboard input and the printer output had to change places. To achieve this a rather large cipher/decipher switch with at least 26 contact points had to be used. The reflector did away with this switch. The machine became symmetrical in the sense that when entering plaintext at a given setting ciphertext would be produced, and if at the same setting the ciphertext was entered the original plaintext would reappear. This innovation had two great advantages. The big switch, with its increased risk of contact failures, was no longer needed, and possible operator errors by using the machine in the wrong mode were removed. However, the reflector had one big disadvantage: a character could no longer encipher to itself; plaintext letter A could not become ciphertext letter A. At first sight this looks like a small sacrifice to pay for such big advantages, however it hides a cryptanalytical wedge, a tool for the codebreaker to master the machine. That a letter cannot encipher to itself means that the process of placing a crib, a possible word or a stretch of guessed plaintext, within a given ciphertext is greatly simplified. Any position of the crib where a letter is found to be at the same position in the crib as in the ciphertext cannot be a valid position and can therefore be discarded. The longer the crib, the easier it is to find the correct matching.

The involutory property of the reflector also hides a cryptological problem. That B = A when A = B, can be exploited in known plaintext attacks, however it would be wrong to criticise ChiMaAG for not seeing this problem in 1923. Even some modern ciphers are reflective, see Boura et al. (Boura et al. 2017)

For some unknown reason the reflector idea was not immediately adopted. On 18

1. The documents referred to in this section are part of the TICOM (Target Intelligence Committee) collections T 1715, T1716, T1717, and T1718 containing original documents from *Chiffriermaschinen-Aktiengesellschaft* (ChiMaAG) and *Chiffriermaschinen-Gesellschaft Heimsoeth und Rinke* (H&R). The collections are in the *Politisches Archiv des Auswärtigen Amts* (PAAA), Berlin. (TICOM 1945b)

2. The more common usage is the term wheels instead of rotors, however here rotors is used to distinguish them from the simple gear wheels used in the counter Enigma.

January 1924, the engineer Paul Bernstein (1891–1976)[3] applied for a patent, DE407804, in the name of *Chiffriermaschinen-Aktiengesellschaft* (ChiMaAG)[4], for a small two rotor cipher machine with glow lamps, but the machine was not equipped with a reflector. Instead the keyboard was connected to the fixed right-hand entry rotor and the glow lamps connected to the fixed left-hand exit rotor, however as the machine did not have a cipher/decipher switch two such machines had to be used, one configured for ciphering and the other for deciphering.

At the exhibition that was part of the 8th Congress of the Universal Postal Union in Stockholm, which ran from 4 July to 28 August 1924, ChiMaAG exhibited two cipher machines. One machine was their big printing Enigma *"Die Handelsmaschine"* (the commercial machine) while the second was a new development called the *Glühlampenchiffriermaschine "Enigma A"* (glow lamp cipher machine "Enigma A") but also going under the name *"Die kleine Militärmaschine"* (the small military machine). (Wik 2018)

The machine was indeed small measuring only 27 x 23 x 13 cm and with a weight of only 5 kg. It was equipped with two 26-point rotors carrying the numbers 01 to 26 on their circumference and a settable reflector with the 26 letters A to Z.[5] This meant the machine had 17576 start positions or message settings but a period of only 676. Another feature of this machine was that all of the lamps and the keys carried removable labels allowing them to represent 26 different letters, numbers or symbols. It was also physically unlike any later Enigma machines because the keyboard and the lamps were laid out in two double rows each of 13 lamps and keys, such that the keys and lamps were in alternating rows. Finally, to move the rotors for each new letter to be enciphered it was necessary to press a separate transport lever (*Antriebstaste*). To avoid two or more letters being enciphered at the same machine setting, all the other keys were physically locked until the transport lever had been pressed and the rotors had moved to a new position. Nevertheless, this was operationally a drawback of this machine.

As Anders Wik explains in his 2018 article the Swedish military was very interested in the two Enigma machines. They even borrowed them for a month for further tests and investigations and when they returned them in September 1924, they expressed an interest in buying fifteen of the small glow lamp machines of type "Enigma A" provided ChiMaAG was willing to make several modifications. The company was very receptive to the proposed changes and by 13 November 1924 they were already able

3. Engineer Paul Alfred Bernstein was born on 14 December 1891, in Debschwitz, Gera, Thuringia. He died in 1976 in Esslingen in Neckar. Information provided by Claus Taaks.
4. ChiMaAG was founded on 9 July 1923, and all the patents and equipment were transferred from *Gewerkschaft Securitas* to the new company.
5. It appears that the machine that was displayed in Stockholm must have been a prototype of "Enigma A" because it was apparently not equipped with a settable reflector.

to offer an improved version of the "Enigma A" and a new model "Enigma B" that had the 28-point rotors and other changes that the Swedish military had proposed. In addition to a fixed reflector, "Enigma B" now had a third rotor that occupied the place of the settable reflector of "Enigma A". With three 28-point rotors the machine period of "Enigma B" was 21168 steps,[6] a big improvement compared with the rather short period of 676 steps for the "Enigma A."[7] Another big improvement was that the movement of the rotors was now performed automatically when any of the keys on the keyboard was pressed; the transport lever of "Enigma A" was no longer needed. While the "Enigma A" could be delivered immediately, ChiMaAG had ten machines in stock, the delivery time was two months for two "Enigma B" machines.

After considerable deliberations the Swedish General Staff decided to order two of the new "Enigma B" machines for further tests and an order was placed on 13 January 1925. However, ChiMaAG had some problems with the construction of the new "Enigma B" and the two machines, A 133 and A 134, were not delivered until 8 April 1925. The General Staff was also interested in the printing Enigma machines and through the Swedish military attaché in Berlin they continued technical discussions with ChiMaAG in the months and years that followed. Their correspondence gives many clues about the company's ideas and plans in these important years. (Swedish General Staff 1924)

On 20 October 1925, ChiMaAG informed the Swedish military attaché Henry Peyron about some of their new developments. In about fourteen days they would be able to show him a new version of their printing Enigma machine, a machine using type bars instead of the rotating print wheel of *"Die Handelsmaschine."* They further informed Major Peyron that for increased security several of their customers were now ordering five rotors with each of their machines so that they would have a choice of 60 different machine wirings rather than only 6 when using three rotors. And finally, they now had an improved version of the small glow lamp Enigma. The new model had: three staggered rows of keyboard keys forming a staircase;[8] a regulator to limit the current in the lamps; and the ability to attach an external battery or power supply. Furthermore, the wooden box now had a proper lock and a carrying handle. The new model was called "Enigma C". A rare photo of this first Enigma C model shows it had

6. The "Enigma B" with its three rotors that used ratchet and pawl movement also exhibited the stepping anomaly of the later Enigma models, hence the period is reduced to 28 x 27 x 28 = 21168 steps. (Hamer 1997)

7. "Enigma A" and "Enigma B" are the correct machine names for the glow lamp Enigma models. The previously erroneous usage of Enigma A and B for the two models of the large printing Enigma machines is unfortunately due to misunderstandings made by early Enigma researchers and collectors. In fact, there were a total of four different models of the early printing Enigma machines.

8. Seen from the side each row of keys sits on a slightly different level forming a three-step staircase. This construction was maintained on all later Enigma models.

serial number A 120. This seems to indicate that while ChiMaAG was preparing the "Enigma B" version with a 28-letter alphabet for the Swedes they were already working on the new and improved model. Like "Enigma B", the C-model had the keyboard laid out in alphabetical (ABCD) order and not in the QWERTZ order that was first used with the Enigma D. This fits well with what we know about the Enigma model ordered by the *Reichsmarine*, which on 1 December 1924 placed an order for ten prototype machines of what it called *Funkschlüssel C* (Radio Cipher C).

The prototype of *Funkschlüssel C* was very similar to the Enigma B delivered to the Swedes. It had 28-point rotors, but a 29-letter keyboard and lamp display where the 29th letter X did not go through the rotors but was connected directly from the key X to the lamp X. Originally the *Funkschlüssel C* was used to superencipher the 4-letter code groups of the *Allgemeines Funkspruchbuch* (A.F.B.). (Marineleitung 1926a; Marineleitung 1926b) The letter X would then have been unenciphered in any code groups containing it. However, in the 1933 regulations for *Funkschlüssel C* the A.F.B. was no longer being used. Messages were now composed from normal plaintext and the letter X was used as a random dummy letter that could be freely added to the plaintext. The use of 4-letter cipher groups was retained as was the case for all later *Kriegsmarine* Enigma traffic.

It turned out that ChiMaAG ran into many problems with the development and production of the new printing Enigma machine, *Die schreibende Chiffriermaschine "Enigma"*, and it was not until 10 March 1926, that Major Peyron was shown the machine. Sweden was still interested in the printing Enigma machines or in a printing machine that was interoperable with the small glow lamp machines. ChiMaAG explained that this was possible, but it would mean a new design of the glow lamp Enigma, which would make this machine both larger and more expensive. The company explained that they had developed such a glow lamp machine but that they had decided to drop it due to its large cost, size, and weight. They further explained that the design principles for the glow lamp Enigma machines were simplified use, ease of transport, low weight, few sources of error, and low price; and that these were design principles they would like to retain.

In the summer of 1926 Lt.Col. Carl Herslow took over as the Swedish military attaché in Berlin. On 21 August 1926, he visited the offices of ChiMaAG to see their latest model of the glow lamp Enigma, Enigma D[9], also called A26 — the 1926 model of the A-series. Internally at ChiMaAG the machine carried the designation Ch. 11, their 11th cipher device, a name that was also used on all technical drawings. The machine he was shown was A 325, which now had four rotors, or more accurately three rotors and a settable reflector. ChiMaAG informed him that the fourth rotor had been added to increase the security of the machine due to requests from certain German

9. There is no doubt that this machine, A26, was called Enigma D, but the name was not used by ChiMaAG after 1926. The new version that arrived in 1927 was always referred to as A27.

authorities and private companies. The machine had already been adopted by the German Foreign Office and was going to be adopted by the *Reichswehrministerium* (RWM).[10] Machines A 316 and A 317 had by then already been delivered to the *Heereswaffenamt* (Army Ordnance Department) for tests and evaluation. Machines A 320 and A 323 were bought by the United Kingdom; A 320 was the machine analysed by Hugh Foss, and A 323 was possibly bought by the Royal Navy[11] for their tests. (Foss 1928) Commercial customers were also interested in the new machine. The Swedish company *Svenska Tändsticksaktiebolaget* (STAB — Swedish Match AB), owned by the financier Ivar Kreuger, bought A 324 as well as A 325 — the same machine shown to Lt.Col. Herslow — and four other machines, A 327, A 328, A 343, and A 344. The price for the Enigma D was 600 RM, equivalent to 143 USD.

On 8 November 1926, Herslow reported that during a new visit to ChiMaAG he was informed about a new development, a device to count ciphertext and plaintext letters. Some customers had expressed an interest in such a counter. He does not give any details about the counter or the glow lamp Enigma models for which it was available, but in a letter to him dated 18 November 1926, ChiMaAG made it clear that machines with a counter were only manufactured on special order. The inclusion of a counter necessitated making the rotors smaller as well as several other internal changes to the machine. Making one such machine would add 250 RM to the normal price of 600 RM and production would take three weeks.

10. The *Reichswehrministerium* was the German Ministry of Defence during the Weimar Republic with overall command of the Army (*Reichswehr*) and Navy (*Marine*).

11. Private communication with the Historian of GCHQ, UK.

The Counter Enigmas

The counter Enigma (*Zählwerksmaschine*) that Lt.Col. Herslow was told about in November 1926 was later patented by ChiMaAG's chief engineer Willi Korn (1893–?).[12] On 9 November 1928, he applied for a patent for the counter Enigma principle; the patent was published on 6 October 1931, as DE534947. (Korn 1931) Then one week later, on 17 November 1928, he applied for yet another patent for the same principle but with some variations. This patent was published 3 July 1933, as DE579555. (Korn 1933)

The idea behind the counter Enigma was more than simply keeping a tally of the ciphertext and plaintext letters. The core idea was to have a machine where the wheels could be moved backwards and forwards in synchronism to allow for easy correction of ciphering errors. With the ratchet and pawl wheel movement used by all the other glow lamp Enigma machines it was almost impossible to move back a number of steps to correct an error. In almost all cases it was necessary for the user to restart from the beginning of the message. The new idea was to strongly couple the rotors closely together using pinion and gear wheels instead of the ratchet and pawl arrangement. With the pinion and gear wheel movement a small crank could be used to move the rotors backwards and forwards through any number of steps in their correct relative positions, while the number of steps was shown by the counter. None of the counter Enigma machines allowed the counter to be zeroed. In their 1927 description of the glow-lamp cipher machine Enigma with counter, ChiMaAG explained that it was not necessary to crank the counter back to zero when beginning a new cipher message. (Chiffriermaschinen AG 1927) They say: "the cipher message can start at any counter position; it is only necessary to note the starting count and then subtract this value from the end count to arrive at the number of enciphered characters."

Using gear wheels for the rotor movement was nothing new for ChiMaAG; from the very beginning their big printing Enigma machine, *"Die Handelsmaschine,"* had used such wheels. The periodic movement of the rotors was produced by using notched gear wheels (*Lückenzahnräder*) where a number of the teeth were missing, producing gaps as explained by C.A. Deavours in his Cryptologia article "Lobsters, Crabs, and The Abwehr Enigma." (Deavours 1997)

12. *Oberingenieur* Richard Georg Willi Korn was born on 31 July 1893 in Rogätz, Wolmierstedt. When and where he died is not known.

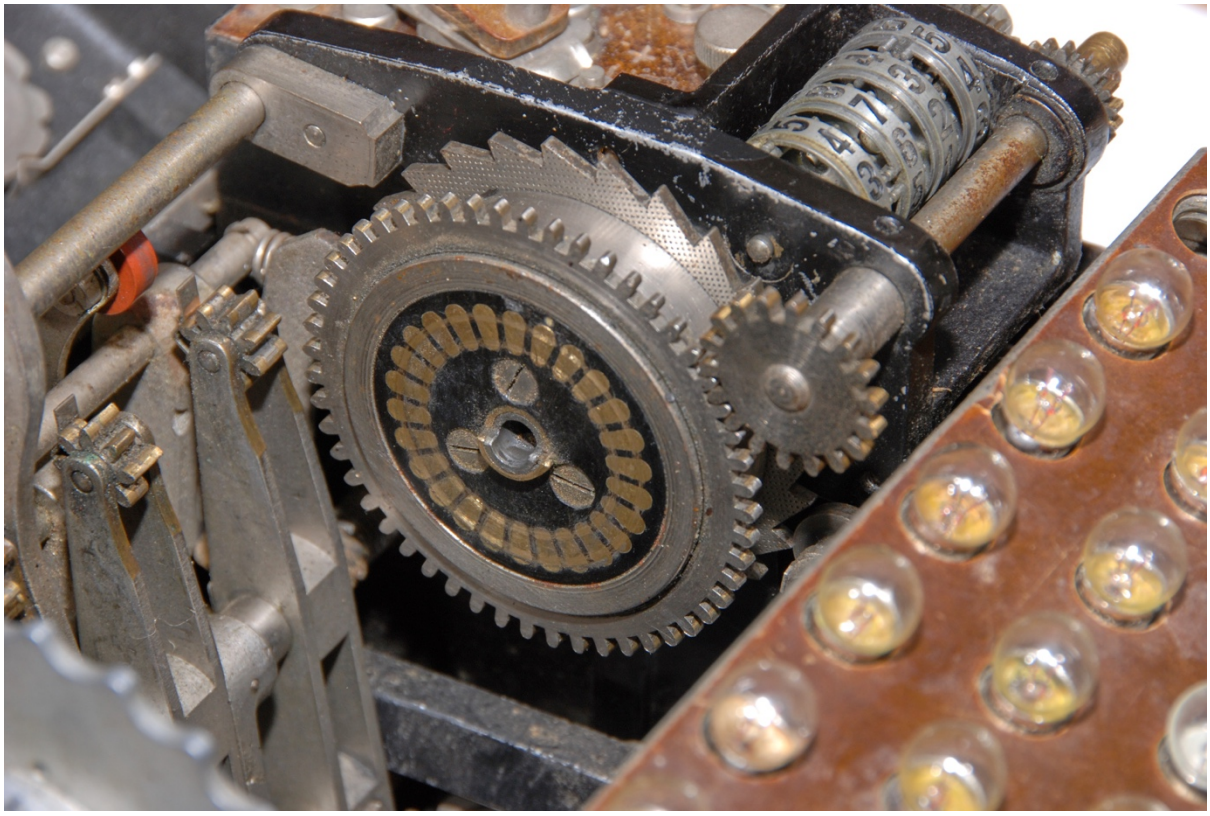

Figure 2. Interior view of *Zählwerks* Enigma G 111 showing the *Eintrittswalze* with the gear and ratchet wheel assembly. Photo © 2019 Paul Reuvers, courtesy of Crypto Museum, The Netherlands.

The first patent, DE534947, was for a machine with rotors having only a single notch. Each gear wheel had only two teeth, which made up the single notch, while the rest of the wheel was one large gap. The notched gear wheel was mounted on the contact plate side, i.e., on the left-hand side of the rotor, while on the contact pin side, i.e., the right-hand side, there was a normal gear wheel with 52 teeth and no gaps, which acted as the rotor's drive wheel. A pinion sat between each rotor and its neighbour and when a notch arrived at the pinion it would engage it and thereby be connected to the drive wheel of the neighbouring rotor. Thus, momentarily, the two rotors would be firmly coupled together and the right-hand rotor would drive its left-hand neighbour one step forward. The drive wheel of the right-hand rotor was coupled via a pinion to another 52-tooth gear wheel that was itself rigidly connected to a ratchet wheel by a short length of tubing. The combination of the tubing and the two wheels was free to rotate around a short stub axle which also served as a mounting point for the *Eintrittswalze*, see Figure 2. The ratchet wheel was moved forward with a pawl each time a key was pressed exactly as in other models of the Enigma machine. Hence each key press was transformed into a smooth movement of the 52-tooth gear wheel that was coupled via the pinion to the drive wheel of the fast, rightmost rotor mounted in the machine and thereby stepped it forward one position.

Because each of the rotors had only one notch the stepping pattern of the first version

of the counter Enigma was cyclometric; unlike the other glow lamp Enigma models with pawl and ratchet movement it did not have the double stepping anomaly of the middle rotor. (Hamer 1997) Furthermore, as in the previous glow lamp Enigma models the notch wheel was fixed to the rotor body and not to the moveable alphabet ring. This arrangement had the disadvantage that the turnover of the wheels would always take place at the same position of the rotor wiring, something that eased the work of the codebreaker. This problem seems to have been discovered by the *Reichswehr-Chiffrierstelle*, the cipher office, which on 1 March 1928, asked ChiMaAG to modify the 400 Enigma machines they had bought so that the notch ring would be fixed to the alphabet ring and not to the rotor body. Precisely this problem was addressed by Willi Korn's second patent, DE579555, which he applied for on 17 November 1928. It is difficult to ascertain today who saw this problem first, the *Chiffrierstelle* or ChiMaAG, because patent application dates do not prove when an idea was born. One indication that not all the ideas in this second patent were Willi Korn's is the fact that his name as the inventor was later removed and only the name of the patent's assigned owner, ChiMaAG, was retained.

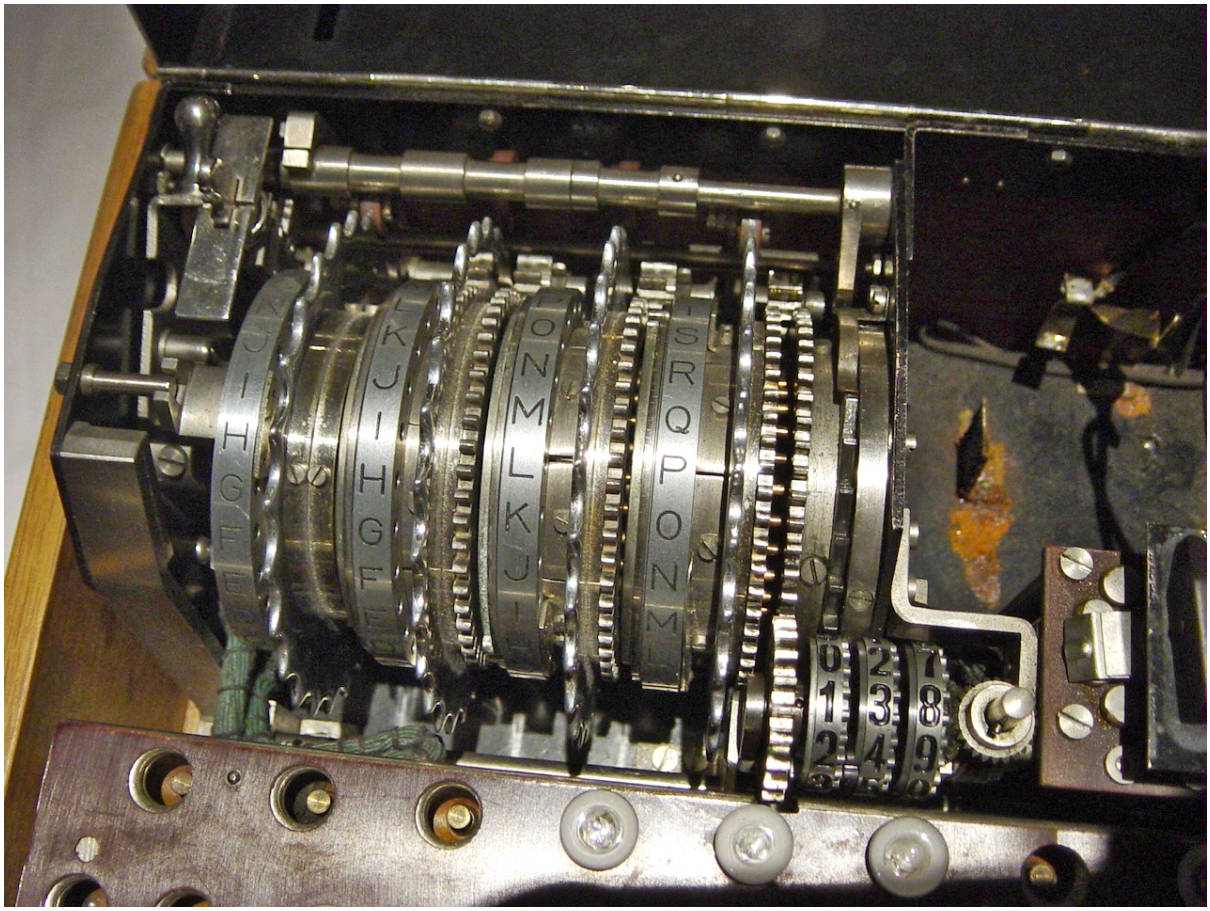

Figure 3. Interior view of *Zählwerks* Enigma A 351 bought by the Swedish Army in February 1927. From the collection of Försvarets Radioanstalt (FRA). Photo © 2007 Ingvar Eriksson, courtesy of FRA.

As we shall see, Willi Korn's second patent also introduced the idea of having multiple notches on each rotor, with their numbers being chosen so as to have no common factors with the rotor's alphabet size, thereby maximising the machine's cycle or cipher period. He further promoted the idea of using a different number of notches for each rotor, with these numbers being relatively prime. But he went even further with his ideas. He also proposed making the notch rings moveable and interchangeable so that either the position of the notches could be changed relative to the alphabet ring, or the whole notch ring could be removed and attached to any other rotor at will. This is indeed a very profound idea, which would later lead to the use of exchangeable rotor cores. Rotors with removable cores were made for the Naval Enigma M4, and the *Lückenfüllerwalze* (variable notch wheel) also had a removable core, but it is not known if this idea of exchangeable cores was ever used operationally.

However, at the same time as the *Chiffrierstelle* addressed the notch ring problem they managed to introduce another error by asking for the notches to be located at different positions for each of the three rotors. Rotor I was to have its notch at Y, rotor II at M and rotor III at D, while earlier each rotor had its physical notch at the same position, namely at G.[13] Where they have different notch positions, it is easy for the codebreaker to use turnover patterns to identify each rotor and its position within the machine.

Like all the early glow lamp Enigma machines, the first counter Enigma had only one notch on each rotor and this was at position G, which was the position used on all of the very early glow lamp models. It is likely that the very first machines that Lt.Col. Herslow heard about in November 1926 also had its notches at G. However, it seems that this machine only had a counter and that the ability to move the rotors both forwards and backwards had not yet been implemented. In their letter of 18 November 1926, ChiMaAG clearly states that the counter had only a control function, i.e., checking the number of enciphered letters at the end of a message to ensure it was correct. Nevertheless, this situation would quickly change. Already by 25 January 1927, Lt.Col. Herslow was able to inform the Swedish General Staff that ChiMaAG had improved the counter Enigma. The rotors could now be moved backwards and forwards in complete synchronism to allow for correction of ciphering errors, etc. The Swedes decided to buy two of these new machines and an order was placed on 17 February with delivery expected at the end of March. However, yet again ChiMaAG experienced unforeseen problems and the machines A 350 and A 351 were not delivered until 12 May 1927.

Everything indicates that these were the very first real counter Enigma machines

13. Since the notch ring was fixed to the rotor body, referring to the physical notch position as G only makes sense when the letter ring is in the neutral position A. The letter G will then be next to where the notch is on the rotor body.

delivered by ChiMaAG. They were equipped with the standard 26-point rotors and looked very similar to the Enigma D machines delivered in that period. The only external differences were a 3-digit counter and the shaft for a crank that was placed to the right of the four rotor windows and adjacent to the switch controlling the lamp currents and the external power supply attachment. On the other hand, opening the top cover revealed that both the rotors and the drive arrangement were very different from the ratchet and pawl movement of Enigma D.

On 10 December 1927, after testing the machines for 6 months the Swedes asked for a quote for 40 – 60 machines of two types, one with and one without the counter, each equipped with 28-point rotors. Four days later ChiMaAG replied with an extensive quote for machines with 26- or 28-point rotors and with or without counter. The price for a quantity of 40 of the normal glow lamp Enigma, A27, without counter and with 26-point rotors was 600 RM each, while the price for the same quantity of a counter Enigma was 700 RM each. Having machines with 28-point rotors increased the cost of each type of machine by 30 RM, while increasing the quantity to 60 reduced the unit price of all models by 20 RM. Additional 26-point rotors for machines with or without counter were respectively 25 and 27 RM each, while 28-point rotors for either type were 1 RM more expensive. ChiMaAG was clearly very eager to have this contract and it ended the offer with these words: "It would be a great honour for us if we could deliver our machines for Swedish requirements."

Unfortunately, ChiMaAG never experienced that honour because the Swedish Army decided to spend their money in Sweden. Instead of the Enigma the Army ordered the B21 machine, designed by Boris Hagelin, from the Swedish company AB Cryptograph. As Anders Wik says: "it is not clear why the B21 was chosen instead of the Enigma, whether the reason was technical, financial or patriotic is not known."

The Swedish Navy, also looking for a modern cipher machine but operating quite independently from the Army, took delivery in April 1929 of three counter Enigma machines with serial numbers A 853, A 854, and A 855. Unfortunately, yet again the available documents do not tell us what the navy did with these machines and what final decision was reached about them. What we know for certain is that no other Enigma machines were bought by the Swedish authorities.

The machines bought by the Swedish Navy were ChiMaAG's latest counter Enigma model, designated as the A28. Externally the most obvious change was that the counter now had four digits instead of three and was placed on the left-hand side of the machine in the space between the rotors and the lamp field. The coupling for the crank was still on the right-hand side next to the fast rotor. However, internally the changes were greater: all the rotors had multiple notches as patented in the second patent, DE579555; rotors I, II and III had respectively 17, 15 and 11 notches; the numbers of notches were relatively prime; and none of them had a common factor with the alphabet size of 26. The numbers of notches were the same as are used in ChiMaAG's printing Enigma machines.

A problem for the Enigma historian is that since the very first glow lamp Enigma was produced all the machines were given serial numbers in what we might call the A-series. Regardless of whether a machine was a model A, B, C or D, or for that matter a *Zählwerksmaschine*, its serial number always began with A. It is therefore often difficult to know whether a machine was a counter Enigma or not, but in some cases it is nevertheless possible to identify the machine and sometimes also its user.

The Chileans and the Dutch

There was no long queue at the door of ChiMaAG of customers wanting the new *Zählwerksmaschine* A28, but it is worth looking closer at a few of the actual buyers. Chile seems to have been one of the first, with an order for two machines A 826 and A 829 probably placed in early 1928. Later in the year they ordered four more machines: A 842, A 843, A 859, and A 860. However, Chile had also ordered 16 of the A27 machines, so in total they had at least 22 Enigma machines. Who exactly in Chile bought these machines we don't know, but most likely they were governmental and probably either the Chilean army or navy. Chile also bought an unknown number of the number cipher machine, *Die Zahlenmaschine*, Enigma Z also called Z30 and internally known as Ch. 16. (Quirantes 2004; Wik 2016)

Other Latin American countries also bought Enigma machines. Argentina bought a total of ten machines, Brazil bought an unknown number, and Mexico bought two; all were of type A27.

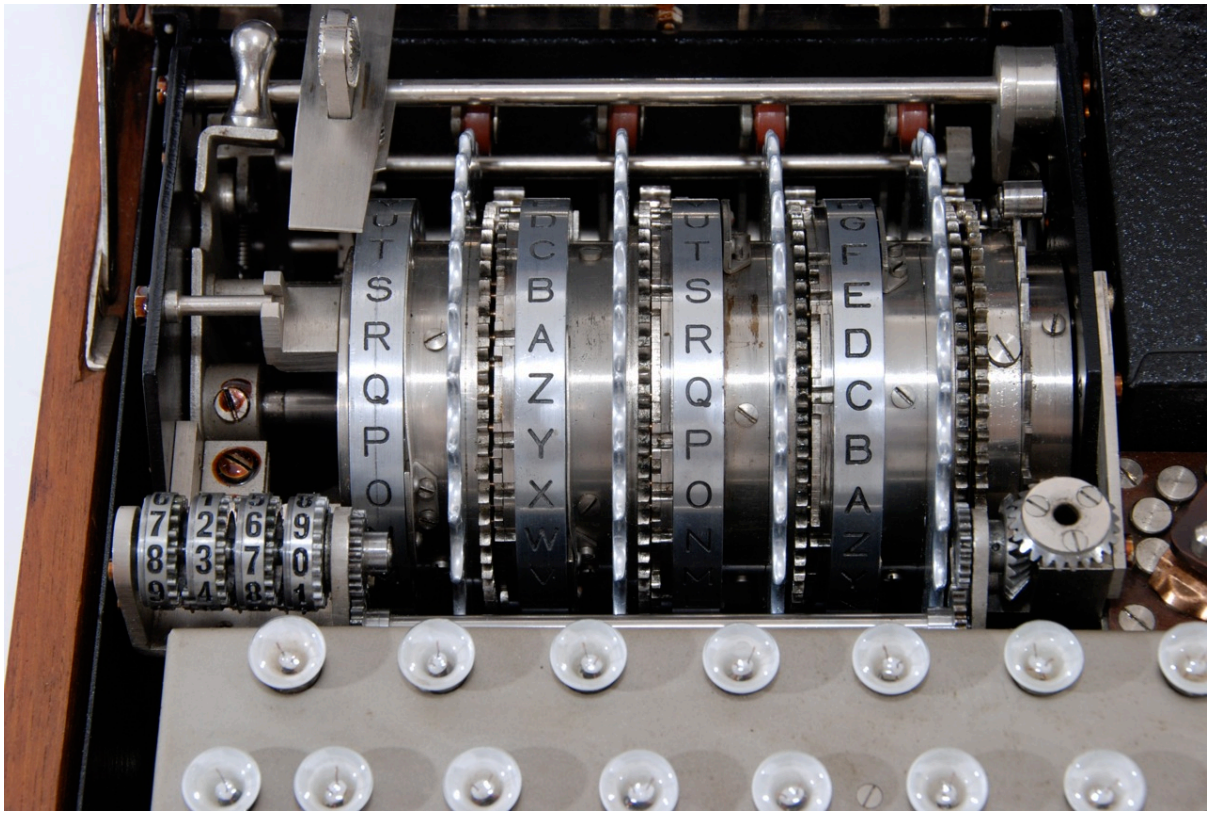

Figure 4. Interior view of Zählwerks Enigma A 865 bought by the Dutch Navy in 1928. Photo © 2019 Paul Reuvers, courtesy of Crypto Museum, The Netherlands.

Another customer that knocked on ChiMaAG's door at around the same time was the Dutch Navy. They bought machines A 823, A 825, A 845, A 856, A 858, and A 865. Looking at the serial numbers it seems that they bought two machines early in 1928 and another four later in the year. The Dutch Navy would turn out to be the user with

the largest number of counter Enigma machines outside Germany; perhaps only the German *Abwehr* had more machines. Altogether the Dutch seem to have had at least 93 of these machines. The majority of them were of a new type that was called Enigma G31 and that was introduced in 1931. We will look at this machine in more detail in a moment.

The first of the Dutch Navy's Enigma G machines was G 128, probably bought in 1931. The next big order was for 44 machines, G 145 – G 188, that was delivered to the Dutch naval base at Den Helder in March 1938. However, we also know that G 138 and G 141 are Dutch naval machines. These machines are not mentioned on a list of all Enigma machines sold to foreign customers dated 21 October 1935, which includes G 128 and all the other machines sold to the Netherlands before this date. Therefore another order for at least four machines must have been made between October 1935 and March 1938. It is also possible that this order was larger than just four machines. In September 1939 they ordered another six Enigma G machines for delivery in February 1940, but the delivery was delayed. It apparently took place on 9 May 1940, one day before the German invasion of the Netherlands, when *Heimsoeth und Rinke* (H&R, as the Enigma company was now called)[14] informed OKH/In 7/IV[15] that they had delivered the machines G 298 – G 303 to the *Departement van Defensie, IVde Afdeeling A*, Den Haag (Dutch Department of Defence). Sometime during the period from March 1938 to September 1939 the Dutch must also have ordered additional machines. All of the Dutch machines were delivered with the commercial wiring.

Scattered information in the Dutch archives refers to twelve machines in the range G 195 – G 220. The distribution is such that it is most likely that all the machines in this range, a total of 26 units, were Dutch naval machines.[16] G 221 was also part of this series. A surviving maintenance booklet shows that the machine was still being used in March 1955. (Koninklijke Marine 1948)

The six machines delivered in May 1940 were most likely recovered by the Germans when they attacked the Netherlands on 10 May 1940. On 28 May 1941, H&R received an order from OKW/WFSt/Stb WNV/Fu II[17] to rewire the two machines G 298 and G

14. *Chiffriermaschinen-Gesellschaft Heimsoeth & Rinke oHG* was officially founded on 31 July 1935. The decision to transform the *Aktiengesellschaft* (AG – public limited company) into an *offene Handelsgesellschaft* (oHG – general partnership) was taken at the general assembly of ChiMaAG on 6 July 1935. Source: *Handelsregisterakte, Landesarchiv Berlin.* (Chiffriermaschinen AG 1952)

15. OKH/In 7/IV (*Oberkommando des Heeres/Inspektion 7/Gruppe IV*) was the German army's signal security group.

16. The information and documents from the Dutch Naval Archives have generously been provided by Andreas Willemsen. Personal communications in 2018—2019.

17. WFSt/Stb WNV/Fu II (*Wehrmachtführungsstab/Stab Wehrmacht Nachrichtenverbindungen/Funk II*) was the department responsible for supplying OKW and

299 to the wiring specification Ch. 15 Tz 136 a – c for the three rotors I, II and III and to Ch. 15 Tz 126 for the UKW. In May 1940 the Germans also found rotor II from G 208 in the debris of the radio station of the bombed out *Alexanderkazerne* in Den Haag. The rotor was sent to OKH/In 7/IV for inspection, where it was found that the rotor belonged to a machine sold legally to the Dutch and that the rotor had the original commercial wiring. (TICOM 1950b) It is possible that this rotor belonged to the set of spare rotors for G 208, because some of the machines were ordered with three spare rotors. It has long been suspected that the Dutch rewired the rotors of these machines. While the special wiring is not known, attempts to break two messages enciphered with one of the Dutch machines have failed when using the normal commercial wiring.

The machines being used by the Dutch Navy in their home waters were ordered by *Departement van Defensie, Afdeeling Materieel Zeemacht* (Department for Naval Equipment), while those ordered by *Ministerie van Koloniën* (Ministry of Colonies) were destined for service by naval units and naval command posts in the Netherlands' East Indies. These machines were ordered specially for use in tropical climates (*Tropenausführung*). The home waters Enigmas were also used onboard Dutch submarines that operated under British command after Germany attacked the Netherlands. But after they lost two submarines, O-13 and O-22, respectively in June and November 1940, it was decided to remove the Enigma machines from all submarines and redistribute them to other Dutch Naval units operating in British waters. Each of the submarines had a three-man Royal Navy liaison team onboard that handled operational traffic using Royal Navy cyphers.[18] It is not known which Enigma was onboard O-13, but O-22 carried the machine G 197.[19] In retrospect it seems that the Royal Navy and the Government Code and Cipher School (GC&CS) missed here an opportunity to examine the very same machine Dilly Knox was trying to breaking during this time. The blame for this oversight can probably be placed at the door of the extreme secrecy that surrounded codebreaking in those days.

All of the Dutch Enigma machines were ordered through N.V. voorheen Ruhaak & Co., Den Haag, that was the representative of ChiMaAG and later H&R in the Netherlands.[20] The Enigma orders seem to have been handled by the former artillery officer Jhr.[21] Frederik Henri Gerrold van Benthem van den Berg (1895 – 1958). He started his work in Ruhaak & Co in 1929, seemingly after he married the daughter of the director, Reinier Ernest van Eibergen Santhagens (1877 – ?).

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government agencies, including the *Abwehr,* with communications equipment.

18. Royal Navy cyphers were in reality superenciphered codes.

19. The loss of these two submarines is still somewhat of a mystery. It is suspected they might have hit mines.

20. Personal communications with Andreas Willemsen in 2019.

21. Jhr. stands for *Jonkheer* an honorific used by the untitled nobility.

The Hungarians

The Hungarians took an early interest in Enigma machines. Exactly when they made contact with ChiMaAG is not known, but in August 1929 ChiMaAG refers to specific offers made to Hungary. In a meeting on 6 August 1929, between *Regierungsrat* (senior civil servant) Wilhelm Fenner (1891 – 1961) and First Lieutenant Walther Seifert (1896 – 1982) of the *Chiffrierstelle* and Frau Elsbeth Rinke (1879 – 1960)[22] and Willi Korn from ChiMaAG to discuss technical details concerning plugboard (*Steckerbrett*) production, ChiMaAG mentioned its intention to use pluggable UKWs on its commercial machines. It explained that the pluggable UKW was both cryptographically and operationally a good solution and that it had already offered such an implementation to Hungary.

However, it seems this solution was not adopted by the Hungarians or for that matter any other commercial customer of the Enigma. The pluggable UKW was adopted and first used operationally by the Luftwaffe in 1944 under the name UKW D. (Marks 2001; Ostwald and Weierud 2016)

On 18 February 1930, Frau Rinke and Willi Korn had another meeting with First Lieutenant Walther Seifert. During the meeting they asked Seifert if he thought it would be possible to use the plugboard on the commercial counter Enigma, *Die Zählwerksmaschine*. That they even asked this question is somewhat astonishing because the plugboard was a secret item and ChiMaAg had signed an agreement with the *Reichswehrministerium* that it should only be used on Enigma machines sold to the *Reichswehr*. On 16 May 1929, they had even transferred the rights of their plugboard patent to the RWM and the patent was then classified as secret. (Chiffriermaschinen AG 1929) Of course Seifert's answer was clear: in his view they would not be allowed to use the plugboard for the counter Enigma either.

Was this idea to use the plugboard on the counter Enigma yet another attempt to find an acceptable solution for their Hungarian customer? We will probably never get an answer to this question. The documentary evidence is very thin on the sale of machines to Hungary. We do not even know who the customer was; however, it seems most likely that it was the Royal Hungarian Army.

What we do know is that Hungary bought an unknown number of the large, printing Enigma machines, called Enigma H and Ch. 14 internally. Other customers of this machine were Argentina, the *Deutsches Stickstoff-Syndikat* (German Nitrogen Syndicate), and the *Reichswehr,* which called this machine Enigma II. The Enigma H machines bought by the *Reichswehr* had the serial numbers H 201 – H 210 and H 216 – H 219, a total of fourteen machines. They were modified to allow them to work as

22. ChiMaAG's Director in those days, Mrs. Rinke, was born Sophie Conradine Elsbeth Schwarz in Sprottau, then part of the Prussian Province of Lower Silesia, on 21 October 1879. In July 1904 she married the artillery officer *Oberleutnant*, later *Major*, Eberhard Rinke.

printers for the glow lamp machine, Enigma I, which was similarly modified. The modified Enigma I machines had the serial numbers A 897 – A 906 and A 932 – A 935. The first ten Enigma H machines were ordered on 9 October 1928, with delivery in March 1929, while the last four were ordered on 4 April 1930, and delivered in August 1930. Who bought the five machines H 211 – H 215 is not known, but they are not likely to have been sold to Hungary. The reason is that one Enigma H, H 221, was discovered in 2005 at the Hungarian Museum for Military History (*Hadtörténeti Múzeum*) in Budapest. (Crypto Museum 2019b) It is therefore more likely that the machines H 220 and H 221, and perhaps others, were sold to Hungary some time in 1931.

This also fits with what we know about the sale of Enigma G machines to Hungary, which seems to have ordered the very first machines in the new series G31. They ordered 24 machines with the serial numbers G 101 – G 124, most probably very early in 1931. All these machines were modified to be connected to the printing Enigma H; the machines being described as "*Zählwerk und Kupplung*" (counter and connection) and given the internal description Ch. 15 b. Ch.15 a was the designation for the normal Enigma G machine. That the machines were indeed modified this way has recently been verified through the discovery of two of the Hungarian machines, G 110 and G 111. (Crypto Museum 2019a) G 111 was put up for sale at a German auction house in 2009,[23] while G 110 was bought as an archaeological relic in Poland in 2017. G 110 was originally in a very poor state without its rotors while G 111 is in rather good condition and equipped with rotors I, II and V. (Reuvers and Simons 2013)

When inspecting the rotors of G 111 one finds that the wirings are different from the normal commercial wirings; only the UKW has the commercial wiring. Either the machines were delivered with special wirings or the Hungarians changed the wirings later. However, most interesting is the discovery that rotor V has seven notches, while rotor I and II have the normal numbers 17 and 15. The question that then immediately comes to mind is: what is the number of notches on the unknown rotor IV? Is it nine?

Another question concerns the number of Enigma H machines the Hungarians bought. It is unlikely to be as large as the number of Enigma G machines for two reasons. The Enigma H with its size and weight is not a machine for use in the field, and also with a cost of 13,000 RM per unit it is unlikely the Hungarians bought more than ten. The Museum for Military History mentions that they once owned three such large machines, of which now only H 221 remains.

In June 1936 we again hear something about the Hungarian Enigma machines. On 3 June 1936, the *Oberkommando des Heeres* (OKH) replied to a letter sent by H&R on 28 May concerning the visit of two Hungarian officers to the Enigma production firm *Konski & Krüger* (K&K). On 6 June Lieutenant Colonel Karl Kelenfy and Captain Tibor

23. The machine failed to reach the expected price and no sale was concluded. Since then the original owner has restored the machine to operational condition.

Csegezy of the Royal Hungarian Defence Ministry (*Honved-Ministerium*) were to visit K&K to fetch parts for their commercial Enigma machines. The letter does not explicitly say Enigma G, but there is no reason to believe they were anything else. In its reply, the OKH had nothing against this visit, however it stressed that the Hungarians were not to be shown any work rooms subject to secrecy.

During the war Hungary was one of the very few countries outside Germany that would receive a few of the *Heeres* Enigma machines with plugboard; the other such countries were Bulgaria, Italy, Slovakia, and Romania. The number of machines and their actual use is not known; however, it is believed they were used for *Wehrmacht* communications with these countries.

In a list of commercial Enigma machines sold to foreign users dated 9 August 1943, Hungary is shown as having also bought machines with the identifier A, most likely A27, the predecessor of Enigma K. Strangely enough, these machines are not included in a similar list from October 1935 even though the sale must have taken place before Hungary bought their Enigma G machines. Nothing else is known about these machines.

The Enigma G

Enigma G was probably introduced in 1931, because the machine was simply called the G31, but no document has been found to put an accurate date on its introduction. It seems that the first machine in the G-series carried the serial number G 101, which was one of the machines sold to Hungary.

Enigma G is a further development of the *Zählwerksmaschine* A28. Cryptographically the machines are the same, but the Enigma G is a physically smaller and more refined machine. While the A28 in its wooden box measures 30 x 28 x 15.5 cm and weighs about 11 kg, the Enigma G measures 27 x 25 x 16.5 cm and weighs only 9.4 kg. The weight of the machine without the case is 7.2 kg.

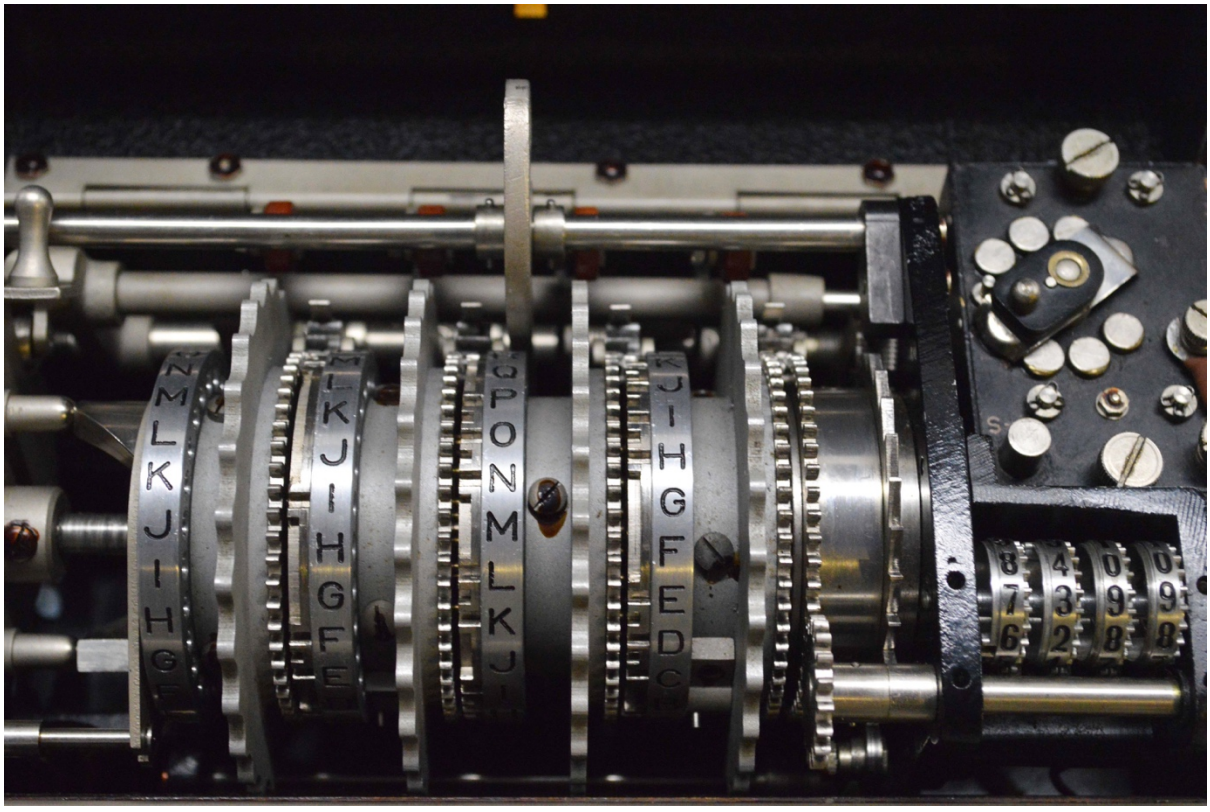

Figure 5. Interior view of Enigma G 312 in the collection of the Bletchley Park Trust. Photo © 2019 courtesy of BPT.

The three fundamental design principles of the A28:

1. High cipher security
2. An easy and also easily learned operating principle
3. High reliability

were also carried forward into the design of the Enigma G. The machine still has a 4-digit counter as on the A28, but its position is now on the right-hand side next to the right-hand rotor. The crank is connected to a shaft in the right sidewall next to the

counter instead of being connected to a coupling in the lid of the machine as on the A28. This means the cranking is now done horizontally instead of vertically, increasing the ease and comfort of using the machine.

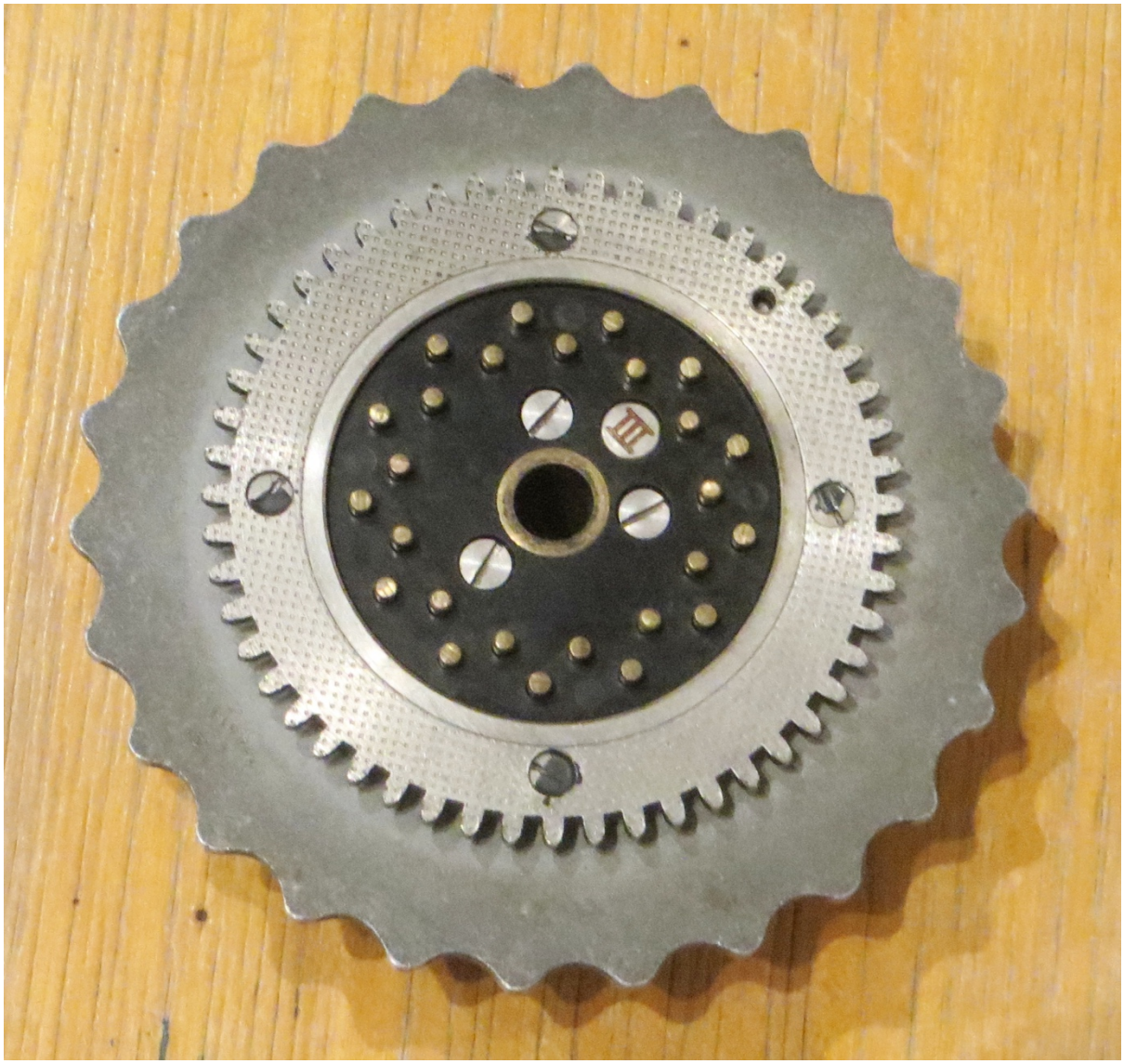

Figure 6. Right-hand side view of rotor III from Enigma G 350 in the collection of Försvarets Radioanstalt. Photo © 2019 Anders Wik, courtesy of FRA.

To make the machine smaller and lighter several design parameters were changed, of which the most striking is the new design of the rotors. The diameter of the Enigma G rotors is approximately 85 mm while that of the normal Enigma rotors is 100 mm. The alphabet ring on the Enigma G rotors is about 62 mm in diameter versus 75 mm for the normal Enigma rotors. To accommodate the 26 spring-loaded contact pins in this smaller rotor, they are not all placed on the same circle. Every second pin is placed on a slightly smaller circle inside the larger, outer circle such that the pins appear to be in a kind of zig-zag pattern. However, due to this layout the shape of the contact plates must also be changed so as to make contact with the pins of both

circles. Instead of being round as on the normal Enigma rotors, the plates on the Enigma G rotors are therefore elongated or pear shaped (see Figures 6 and 7).

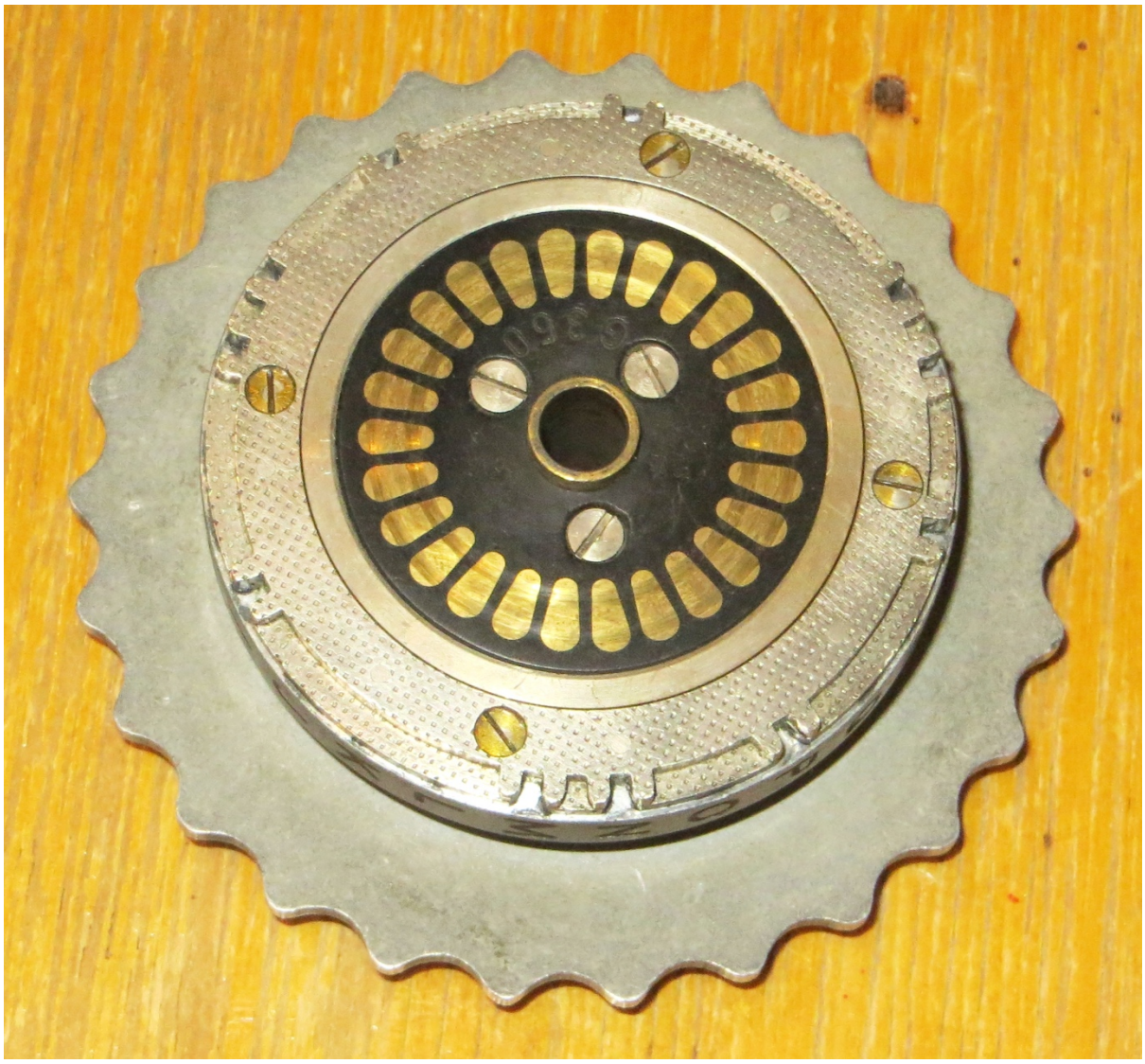

Figure 7. Left-hand side view of rotor III from Enigma G 350 in the collection of Försvarets Radioanstalt. Photo © 2019 Anders Wik, courtesy of FRA.

So far, no documents have been found that indicate clearly why this new version of the counter Enigma was made. Because the machine neither changes the cryptographic principle of the A28 machine nor increases its security, it seems likely that the weight and size of the old machine must have been the reason for the new design. Was it triggered by a demand from one of the customers? If so, most likely it was the Hungarians who were looking for a smaller, lighter machine for their Army. They were an important customer in those days and they also bought the first 28 machines that were delivered. Of course, the Dutch were also interested in the counter Enigma and it is quite possible they too preferred a smaller and a lighter machine for their ships and stations overseas. However, in the minds of ChiMaAG the counter Enigma was primarily a commercial machine, and it is possible that it

represented their attempt to position themselves in the competition with another maker of such machines, Alexander von Kryha and his Kryha machines. Kryha's two main models were a commercial version ("*Typ Commerce"*) and a diplomatic version ("*Typ Diplomat"*). Their dimensions are respectively 25 x 20 x 10 cm and 30 x 30 x 14 cm, with a weight of 4.5 kg for the commercial model and 6 kg for the diplomatic machine. Documents from H&R show that they were interested in Alexander von Kryha; two memoranda from 1934 addressed to the *Reichswehrministerium, Chiffrierstelle* contain information about von Kryha and his machines. (Marks 2011; Schmeh 2010)

With Enigma G ChiMaAG now had a product that in size and weight could compete with Alexander von Kryha's machines and that cryptologically was greatly superior to them. However, they also made modified versions of the Enigma G. On 9 July 1936, the chief engineer of H&R, Willi Korn, prepared a note for Captain Kopp of OKH/In7 and presented it to him the next day. It covered a variety of subjects including the counter Enigma, the new UKW B, Enigma operating instructions, delivery of Enigma M to the navy, questions about a device for Fritz Menzer (Mowry 1983), and concerns about requests from representatives from the Japanese Navy in Berlin for information about cryptography. The first point, concerning the Enigma G (*Zählwerksmaschine Ch. 15*), gives an interesting glimpse of H&R's development of this machine. Korn mentions that they had three special versions of this machine in their offices.

a) 1 pc. of Ch. 15 a, the normal model with a driven UKW, but having special wirings for the rotors and the UKW.
b) 2 pc. of Ch. 15 b, also with a driven UKW, but additionally equipped with a printer connection.
c) 2 pc. of Ch. 15 c, equipped with a fixed UKW and a plugboard.

Points a) and b) refer to the normal Enigma G and the special version with a printer connection that was delivered to the Hungarians, but point c) is somewhat astonishing. Because the plugboard (*Steckerbrett*) was a secret invention which ChiMaAG had agreed to only use on machines delivered to the *Reichswehr*, the Ch. 15 c machine must have been developed with this agreement in mind. A question is then: was this only a prototype development, or did they deliver a small series of such machines to a *Reichswehr* office? That the plugboard was added is understandable if the intent was to increase the security of the machine, but why did they equip the machine with a fixed UKW? However, another explanation is perhaps more likely: that the plugboard was connected to the UKW and not to the entry wheel (*Eintrittswalze*). This explains why the UKW was fixed and also how such a machine could be equipped with a plugboard without violating the *Steckerbrett* agreement with the *Reichswehr*. This fits very well with what we have already seen about ChiMaAG having already offered a pluggable UKW to the Hungarians in August 1929. It also means that the two versions mentioned in points b) and c) above were probably both prototypes being prepared for presentation to the Hungarians.

The note for Captain Kopp concerning the Enigma G versions was in reality an unofficial offer to service and modify the five machines so that they could intercommunicate. It seems that Captain Kopp was looking for a quick delivery of a few Enigma G machines for some unknown purpose. Korn explained that the machines could be made ready in about eight weeks and that they would be offered cheaply; however, this was intended as an exceptional offer without setting any precedent for the future. His statement shows clearly that in July 1936 H&R did not expect to sell any more special versions of the Enigma G machines to Hungary, or for that matter, to anyone else. The models Ch. 15 b and Ch. 15 c had come to the end of their life; all future production would only be of the normal version of the Enigma G31, model Ch. 15 a.

Abwehr and Other Users

We have looked in detail at the foreign commercial and government users of the counter Enigma, but the German government and armed forces also used this machine. The first known German official use of the machine dates from July 1936 when a new special wiring for the UKW was created with the drawing number Ch. 15 Tz 115. However, it is possible that other official German users may have used the machine before then; indeed, it is quite likely because the drawings for the wiring of the commercial rotors and UKW were labelled respectively Ch. 15 Tz 69 a – c and Ch. 15 Tz 70 and therefore there is a large gap in the drawing numbers between Tz 70 and Tz 115. If the Hungarian machines were, as we believe, delivered with special rotor wirings their drawing numbers most likely lay in this range.

If we include the wiring of the rotors and UKW for the commercial version of the Enigma G machines, then there is a total of 22 different rotor wirings and five different UKW wirings. Many of these were probably used by the German *Abwehr*, which was undoubtedly the largest official German user, but several other wirings must have been intended for other users who so far remain unknown. Two exceptions are the German commercial firms *Deutsches Stickstoff-Syndikat* (DSS) and *I.G. Farben*. DSS used Enigma G and the large printing Enigma H machines in their communications with Japan, while *I.G. Farben* used Enigma G for their communications with Asia and their office in New York. The special wirings for the *I.G. Farben* machines are Ch. 15 Tz 121 a – c for the rotors and Ch. 15 Tz 122 for the UKW, both wirings created on 14 November 1938. Some of the *I.G. Farben* machines were G 222 – G224, G 256, G 257, and G 404 – G 407. However, *I.G. Farben* had already bought Enigma machines in 1930 and 1931. In 1930 they took delivery of the machines A 837 and A 838, while in 1931 they received A 839 and A 840. It is most likely that these deliveries were for four machines ordered at the same time, but with two of them being delivered in December 1930 and the other two in January 1931. ChiMaAG lists these machines as being of the normal commercial type A27 and it is likely that they were delivered with the normal commercial wiring.

Another known user of Enigma G was the German Armistice Commission (*Deutsche Waffenstillstandskommission*, DWStK) in France and North Africa. (US Coast Guard 1943) One of these machines, G 292, which the Germans called the KK-machines, was captured by American and British commando units during the Operation Torch in French North Africa at the beginning of November 1942. (Hammarborg 1954; Trevor-Roper 1942) The machine was used to encipher the traffic that passed between Algiers, Casablanca, Oran, and Tunis in North Africa, and Bourges, Marseilles, Toulon, and Wiesbaden in France and Germany. In November 1942 the traffic on this network was about 30 messages daily, but following the fall of North Africa only the French stations remained, at which point the traffic dwindled to about five or six messages daily. The physical wiring of this machine is known, but the

corresponding drawing designation remains unknown even though it is possible to guess at a few likely candidates.

It appears that this machine was the only operational machine of this type available to the GC&CS codebreakers at BP. Because American forces had originally captured the machine, the US Army's chief cryptologist at the time, William F. Friedman, wanted it returned to the US. However, Peter F. G. Twinn, who became head of Dilly Knox's group when he died in February 1943, was reluctant to part with the machine. As Twinn says in his memo to Gordon Welchman dated 27 September 1943: "I should be extremely reluctant to part with this German *Abwehr* Enigma now in our possession." One of his reasons for not parting with the machine was the following: (Twinn 1943)

> We continually break messages on signatures at the end of long messages and in order to arrive at the beginning with the correct number of turn-overs, (an involved sum on this type of machine) we use the counter and winding handle which are its main feature. Moreover this is the only one we have which will produce the correct turn-over sequence both forwards and in reverse.

The interesting thing to note here is that the machine's counter and crank, which was meant to ease the task of the operator when ciphering his messages, seemingly also eased the task of the codebreaker attacking the very same traffic.

The DWStK had close ties to the *Abwehr* and several of its staff in North Africa were in fact *Abwehr* agents reporting back to the *Abwehrstelle* (Ast) in Wiesbaden, where the DWStK was headquartered in the impressive Hotel Nassauer Hof. This close collaboration might explain why the DWStK also used Enigma G. (Kolisch 1946)

Two other special cases are known of Enigma G machines being used by German signal intelligence agencies. The machines G 249 and G 250 were used by OKH/In 7/IV for communications with the General Staff of the Italian Armed Forces. OKW/Chi also had contact with the Italians. They used the machines G 247 and G 275 to communicate with the Italian Military Attaché. (TICOM 1950a)

On 1 August 1946, Dr. Erich Hüttenhain and Dr. Walter Fricke delivered a piece of "homework" (TICOM 1945a) on the *Zählwerk* Enigma that they had been assigned while they were being detained at CSDIC (UK)[24] for extensive and in-depth interrogations. Drs. Hüttenhain and Fricke were normally good and well-informed witnesses on German cryptology, but their report shows clearly that they had very little knowledge of the Enigma G. They were not quite sure how the machine worked. They could not remember whether the fourth wheel, the reflector, was driven or not, and they believed the number of rotor notches varied from 7 to 13 rather than the

24. CSDIC was the "Combined Services Detailed Interrogation Centre", a set of facilities run by the British War Office (specifically MI19) between 1940 and 1947.

correct values, from 11 to 17. Perhaps they were thinking about the Hungarian Enigma G machines which had five rotors and where rotor V had seven notches and rotor IV most likely had nine. If so, does this imply that OKW/Chi had been attempting to read Hungarian Enigma G traffic?

They mentioned that Enigma G is more secure than Enigma K, and that the simpler method of breaking Enigma K, the so-called *E-Leiste* or E-strip,[25] could not be used against the counter Enigma because the *Ringstellungs* could not be ignored when making up the strip. On machines with rotors having only one notch per wheel this was possible.

Interestingly, they also mentioned that when the weaknesses of the *Zählwerk* Enigma became known the idea of adding a plugboard (*Steckerbrett*) to the machine was turned down; procedural changes to increase security were adopted instead. Hüttenhain and Fricke listed two proposed changes:

a) Double encipherment of each plain text. The basic wheel settings for the second encryption would be kept the same for the complete day.
b) Encipherment by Enigma G after first enciphering the plain text using a simple columnar transposition with a numerical key for selecting the order of the columns.

Here their information is correct, probably because it was a relatively new development, starting in autumn 1944, and something they had probably learned directly from *Regierungs-Oberinspektor* Fritz Menzer (1908–2005), (Mowry 1983) who at this time had become seriously concerned about the security of the G31 machines. BP first encountered use of this method on 20 October 1944, on the *Abwehr* link between Berlin and Madrid. BP did not immediately discover what prevented breaking of the traffic, but on 31 October it was discovered that the messages had first been enciphered on the key of 20 October before it was again enciphered on the key of the 31st. But it was also discovered that before any encipherment on the Enigma G the plaintext was first transposed using a cage or rectangle of four 5-letter groups, a width of 20 letters, that was filled in with the text before the columns were read out and doubly enciphered on the Enigma G. This procedure of course removed all word and bigram statistics from the plaintext and prevented the use of cribs to solve the message. (Batey et al. 1945)

Hüttenhain and Fricke then attempted to give some information about the operational use of the machine, however here their ignorance was again evident. They stated that only a small number of Enigma G machines were made, approximately 100 units in their estimation, while as we shall see more than 300

25. The *E-Leiste* was produced by repeatedly enciphering the cleartext letter E at all positions for a given wheel order of the machine. Ciphertexts were then slid along the E-strip until one obtained an agreement of approximately 15–20% between the overlapping E-strip and ciphertext. This position then indicated the correct wheel position.

machines were produced. They then mentioned that two years previously, which would mean sometime in 1943, the Enigma G machines used by the German military attachés were withdrawn from use and replaced by *Heeres* Enigma machines with *Stecker*. This is quite possibly true. We know that the military attachés used specially wired *Heeres* Enigma machines for their communications towards the end of the war, but we still know very little about what cryptological systems they used before and at the beginning of the war. However, Hüttenhain and Fricke then claimed that Ag WNV/Fu[26] collected all the machines previously used by the military attachés and gave them to the *Abwehr*. They added that they did not know whether the *Abwehr* put the machines into operation. It is quite possible that the military attaché machines were indeed offered to the *Abwehr*, but the *Abwehr* had started to use Enigma G well before 1943.

Dilly Knox made his first break into the *Abwehr's* Enigma G machines at the end of October 1941, and the first complete message was broken and deciphered on 8 December 1941. (Batey et al. 1945; Batey 2009) Internal documents from the Enigma company H&R show that the rotor wirings for the main *Abwehr* machine used in Europe, called Group II by BP, were dated 12 March 1940. However, it is most likely that a previous version of the Group II machine dates from 19 June 1939. This matches well with the information that in July 1941, Dilly Knox took over an accumulation of *Abwehr* traffic dating back to December 1939. (Batey et al. 1945) Other Enigma G machine wirings date from August 1936 and December 1938, but whether these were for the *Abwehr* or some other users is not known.

To better understand the *Abwehr's* need for and use of cipher machines it is interesting to take a closer look at their communications. From very early on the *Abwehr* had an extensive communication network inside Germany, in the occupied territories, and abroad in the neutral countries. Rudolf Staritz, who was a radio operator with the *Abwehr* during the war, has estimated that they had 80 officers, 730 non-commissioned officers and 1850 radio operators. (Staritz 2018) Both radio and wire communications for all *Abwehr* departments were managed by Section (*Referat*) Ii[27] under the command of *Oberstleutnant* Rasehorn, who was replaced in March 1944 by his deputy Major Theodor Poretschkin (1913–2006). This change was probably linked with Hitler's order of 12 February 1944, that the *Abwehr* should be taken over by the *Reichssicherheitshauptamt* (RSHA — the Reich Security Headquarters) and integrated into their *Amt Mil* (Military Department). However, Major Poretschkin did not become the commanding officer of Mil E, the new communications section, as planned; instead *Oberstleutnant* Wilhelm Boening

26. Ag WNV/Fu (*Amtsgruppe Wehrmachtnachrichtenverbindungen / Funk*) was the new name for the previously mentioned Stb WNV/Fu (*Stab Wehrmachtnachrichten-verbindungen / Funk*), see footnote 17.

27. Referat Ii is *Amt* (department) — Roman number one, section — letter 'i', which dealt with communications.

(1897–?) was installed as the combined leader of Mil E, F, and G. Major Poretschkin became Boening's deputy and later he received the command of *Nachrichten-Regiment* 506 (NaRgt. 506) when it was created on 15 September 1944. (Kampe 2008) Mil E was the administrative section and can be said to have existed in name only. The real work of running the communications of the *Mil Amt* (*Abwehr*) was done by NaRgt. 506, headquartered at Stahnsdorf in the district of Teltow in Berlin. In March 1945 it moved to Eisenberg in Thuringia before finally ending up at Obing in Bavaria. Altogether the *Abwehr* operated close to 40 large radio stations in Germany, the occupied territories, and abroad. The principal station for administrative traffic was located at Belzig near Dessau and codenamed BURG, Stahnsdorf had a local station called SCHLOSS, while the other main stations were at Hamburg-Wohldorf (DOMÄNE), Wiesbaden (WILJA), Köln (KONRAD), and Sigmaringen (SONJA). Stations communicating with the *Abwehrstellen* (Asts) of the army groups and armies on the Eastern Front were located at Nikolaiken (ATLAS) and at Sulejowek (WALLI) east of Warsaw. Of the stations abroad the most important were Madrid (SABINE), Lisbon (LINA), Rome (TOGO), Merano (JACOB), Paris (PAUL), and Vienna (WERA). In addition to these main stations some of them operated secondary field stations working as relays for traffic to more distant regions. Hamburg-Wohldorf (DOMÄNE) had such stations at Arachon, Cherbourg, and Libourne in France, while OTTO, the *Abwehr* station in Oslo, controlled five field stations in Norway. The person responsible for issuing callsigns, frequency plans, and code and cipher material for all *Abwehr* communications was *Oberleutnant* Alfons Oesterle (1914–?) based at Stahnsdorf. He worked in close collaboration with *Regierungs-Oberinspektor* Fritz Menzer of OKW/Chi on all questions of cryptography and with *Oberleutnant* Heine of OKW/WNV/Fu III concerning *Funkabwehr*[28] — radio counter intelligence. (Wenzel 1946)

The communications of the internal *Abwehr* network were initially enciphered using the Enigma G. Towards the end of the war they began to use the *Schlüsselgerät 41* (SG 41), the KD Enigma, an Enigma K equipped with both the pluggable UKW D and specially wired rotors having nine notches, and in a few cases standard *Heeres* Enigma machines. Those stations communicating directly with *Abwehr* agents in the field used a variety of hand ciphers, both substitution and transposition ciphers, and in a few cases specially wired Enigma K machines. For communicating with agents in South America, where the traffic was handled by controlling stations in Mexico, Chile, and Argentina, they used hand ciphers, the Kryha machine, and the Enigma G. (Marks 2011)

The *Abwehr* had networks in South America from an early stage. Brazil, Chile, and Argentina were countries with large networks, but which generally were rather unproductive and that were also quickly were broken up or greatly reduced by the

28. The *Funkabwehr* was tasked with discovering and locating illicit radio transmitters operating in Germany and the occupied territories. (Radio Security Service 1946)

local authorities. (Mowry 2011) In Argentina the *Abwehr* and the *Sicherheitsdienst* (SD) ran three joint networks that they codenamed *Grün* (Green), *Rot* (Red) and *Blau* (Blue). The Enigma G machines used by these networks were therefore called Green, Red and Blue by BP and the US Coast Guard's Unit 387, both of which worked on breaking the machines and deciphering the traffic. (Batey et al. 1945; US Coast Guard 1945)

Two of the "Green" *Abwehr* machines carried the serial numbers G 227 and G 228. They were wired on 10 July 1943, but the rotor wirings Ch. 15 Tz 125 a – c, were most likely created in 1939, while the UKW drawing, Ch. 15 Tz 115, is dated 14 July 1936. This mix of newer rotor wirings with older UKW wirings is a typical characteristic of the *Abwehr's* Enigma G machines. The reason is of course that there seem to have been only five different UKW wirings, the oldest being the commercially wired UKW, Ch. 15 Tz 70, from 1931, and the youngest, Ch. 15 Tz 132, dating from 14 March 1940. (TICOM 1945b)

The two other G31 machines used in Argentina were codenamed Red and Blue. The wiring of the Blue machine was never recovered by BP or US Coast Guard Unit 387; however, the wiring of the Red machine was recovered cryptanalytically by both BP and Unit 387 more or less simultaneously. Three of the machines are known, G 209, G 260 and G 263, but the drawing IDs for the rotor wirings remain unknown. Curiously enough the Red machines used the commercial UKW, Ch. 15 Tz 70. The first of these machines to be prepared for service was G 209, which was also the first Red machine to arrive in Argentina. G 209 was the machine with commercial wiring that we believe had previously been sold to the Dutch and then recovered by the Germans when they occupied the Netherlands. The order for the preparation of this machine, dated 4 August 1943, mentions that the machine should be checked out and rewired according to the drawing submitted to chief engineer Willi Korn. The order for the wiring of G 260 and G 263 came one week later on 11 August, with the instructions for them to be wired in the same way as G 209.

Initially communications using the new Red machine G 209 could not be deciphered by the agents in Argentina because Berlin made a serious error and enciphered the messages on the wrong machine: one equipped with the Red rotors but having a different UKW, Ch. 15 Tz 115 — the Green UKW. Initially BP and Unit 387 thought the Red rotors had simply been put into a machine with the wrong UKW, but later it would turn out that Berlin had used a machine with a valid combination of rotors and UKW, but one that was intended for use on a completely different radio circuit. This became apparent when it was discovered that the SD in Europe used a machine with the Red rotors and the UKW Ch. 15 Tz 115. The first use of this machine was observed in the summer and autumn of 1944 on an SD link between Berlin and Tirana. In the latter part of the war this machine also appeared in SD traffic between Berlin and Madrid.

The UKW, Ch. 15 Tz 115, was used in many of the specially wired Enigma G machines.

It was used in two series of machines having the serial numbers G 312 – G 317 and G 189 – G 194. These two series have different rotor wirings but share the same UKW. Whether they were used by the *Abwehr* or by other users is so far unknown. In total this UKW, Ch. 15 Tz 115, was used in at least ten different sets of machine wirings.

The Last Days of Enigma G

Enigma G was only made in relatively small numbers; the first machine was G 101 and the highest serial number that has been found in the available documents is G 426. It is therefore likely that less than 350 machines were produced. The design of this machine with its large number of gear wheels was undoubtedly expensive to produce under wartime conditions. H&R expressed this view in a letter to OKW/Chi dated 23 February 1943, which presents H&R's latest secret patent, C 58002 IX b/42 — C 8511 Gm 42 n, for their invention of a new and improved pluggable reflector, an improved UKW D, that the present authors, for lack of a better name, have decided to call UKW Plus. The new reflector would have the following important advantages:

a. All 26 reflector contacts could be freely interconnected in pairs using 13 wires.
b. The reflector could be set in any of its 26 different positions with respect to the other rotors.
c. The reflector would be driven during operation exactly like the other rotors.

They stress that their new pluggable reflector would have full freedom of interconnections and not be limited to just 24 contact points as on UKW D. This meant that UKW Plus could also reproduce the connections of the fixed UKW B and therefore allow machines with the new reflector to be fully compatible with older machines using UKW B. They thought their new invention would be of interest for use in the existing *Heeres* and *Marine* Enigma machines as well as in the Enigma K and Enigma T machines already introduced into the *Wehrmacht*.[29]

They even suggested that for Enigma machines equipped with a plugboard (*Steckerbrett*), rotors with variable notches (*Lückenfüllerwalzen*), and the new driven, settable, and fully pluggable reflector there would no longer be any need for the extra rotors IV and V; the basic machine would have sufficient cipher security even without the extra rotors. Furthermore, they posed the question of whether it would now be advisable to use the same new Enigma model for both the Army and the Navy. They claimed that the advantage of such standardisation was obvious.

They proposed pushing the standardisation even further and using UKW Plus in the Enigma K machines deployed for *Wehrmacht* purposes, because apart from the plugboard these machines were, in most parts and construction, identical to the *Heeres* Enigma. And they also proposed replacing the Enigma G, which until then had been used for special purposes and for which small-scale production in war time was now longer profitable, with these new machines utilising UKW Plus.

The reaction that H&R's proposals received at OKW/Chi is unfortunately not known,

29. In the existing machines UKW Plus would be a mere replacement for their normal UKWs. In the Enigma K and T versions it would be settable, but to make it driven would necessitate extensive modifications of the existing machines.

and their new invention UKW Plus seems not to have been implemented, at least not in a *Wehrmacht* machine. However, H&R's ideas for standardisation were aligned with those of OKW/Chi and at the end of the war plans for a new, standard *Wehrmacht* rotor machine were in various stages of development. Perhaps someone also noticed H&R's comment about the unprofitable production of Enigma G under war time conditions, because nine months later, on 17 November 1943, H&R and K&K each received a letter from the Plenipotentiary for Technical Communication Equipment (*Der Generalbevollmächtigte für technische Nachrichtenmittel, GBN*) informing them that in a meeting of the Enigma users it was decided, as a step towards unified production of Enigma cipher machines, to stop immediately the production of the Enigma G and Enigma K machines. The 180 Enigma T machines then in production were to be completed with delivery by the end of January 1944. Production indeed stopped, but existing machines, both Enigma G and K, continued to be repaired and their rotors rewired, etc., until the end of the war.

Due to the small number of Enigma G machines produced and the very small number of them that survived the war, with one known exception the machine never saw post-war use. The Dutch Naval Enigma G machines continued to be used after the war and it is known that they were in service at least until the end of the 1950s. (Koninklijke Marine 1948) It has been reported that most of the Dutch machines were destroyed sometime in the 1970s, and today only eight machines survive in Dutch government collections.[30] Whether the Hungarian machines saw any post-war use is not known.

30. Private communications with Raul Reuvers, Crypto Museum, The Netherlands.

The History of G 110

Enigma machine G 110 was acquired by the Bletchley Park Trust (BPT) in 2016 from a private individual who had in turn bought it from a source in Poland. The machine was apparently discovered in southern Poland near the Czech border, allegedly dug up in a farmyard. Unfortunately it was not possible for BPT to verify the exact location or circumstances of its discovery, or indeed how many hands it passed through before being acquired by the Trust. However the details of the object itself, and the numbers and markings revealed during the conservation process, allow some of the history of the object to be reconstructed.

When G 110 fell into the hands of Bletchley Park it was in rather poor condition. Its provenance suggested that it had been buried in the ground for around 70 years. When it was received at Bletchley it had not been subject to any systematic cleaning or conservation and bore the traces of its sojourn as a buried archaeological object. It was significantly corroded, and still contained areas of compacted mud and organic debris, particularly in its interior. After a short period on display at Bletchley Park in its unrestored condition the decision was made to have the machine professionally cleaned and conserved. This would serve a number of purposes:

- The condition of the machine could be stabilised and further decay prevented as far as possible.
- Detailed examination of the surviving parts of the machine might reveal useful information about its origin and history (which was indeed the case).
- The machine would be more suitable for public display in its conserved state.

The machine was passed to Ian Clark Restoration, a company of specialist conservators with particular expertise in industrial and maritime machinery collections, as well as conservation of decorative metalwork. In total over 100 hours of conservation work was carried out on the machine. Despite its rather unpromising initial appearance the conservator found that the machine was 'surprisingly stable and did not show any immediate signs of structural failure or loss of physical integrity.' Allowing for the time it had spent buried he observed that it had survived 'remarkably well.' (Clark 2018)

However, it did show signs of having been deliberately disabled prior to being disposed of at the end of its working life. In particular the three encryption rotors and the reflector had been removed from the machine and discarded separately, presumably for reasons of cipher security. It is possible that this had been carried out with some force, as the right-hand pawl and ratchet wheels and the *Eintrittswalze* had become detached from the machine frame and were loose in the body of the machine, retained only by the wiring loom. The counter mechanism on the right-hand side along with the battery and its connecting wires were also absent. The glass from all the bulbs on the lamp board was missing, along with the translucent letter panels,

although the lamp board itself was still in good condition. Most of the keys were in situ, and their labels legible, although the lenses were cracked and discoloured. Only the 'F' and 'H' keys were missing from the central key row. The machine was also lacking its original wooden carrying case.

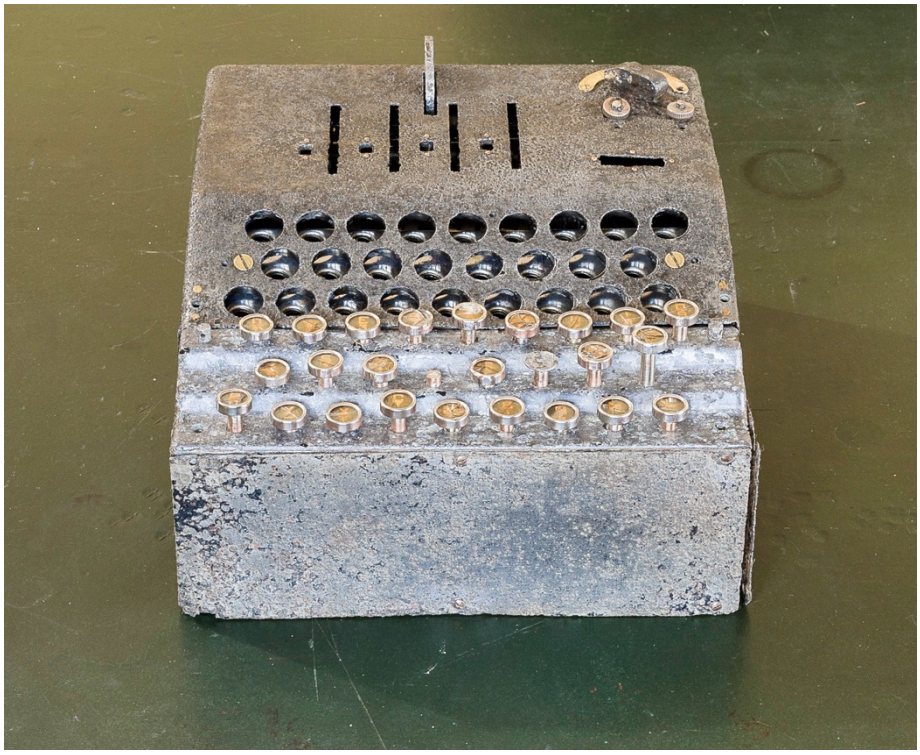

Figure 8. The restored Hungarian machine G 110 in the collection of the Bletchley Park Trust. Photo © 2019 Will Amlot, courtesy of BPT.

The machine was first mechanically cleaned using brushes, scalpel and bamboo picks, to remove as much as possible of the organic debris. This was followed by careful disassembly of the machine where possible to allow further cleaning and assessment of the individual components. The principal parts of the machine were then subject to repeated sequences of immersion in Biox Liquid for periods of up to 4 hours and washing with de-ionised water. Biox is a biological oxide corrosion remover, completely harmless to humans and containing no strong acids or alkalis. It is used by conservators for the sympathetic removal of rust, tarnish and verdigris from iron, copper, brass and aluminium objects. After this process was complete the surfaces were sealed with several coats of micro/crystalline wax. The non-ferrous parts of the machine such as the keys, lamp board, switch labels and internal parts such as the plug socket and drive mechanism were also cleaned and polished using Autosol metal polish before receiving their own coat of wax sealant. The machine was then reassembled, including refitting the *Entrittswalze* and its drive wheels in their correct position.

The results of this process were readily apparent when the machine was returned to Bletchley Park. What had been a brown rusty box was now clearly a cipher machine.

Most of the original lacquer on the exterior of the machine had been lost due to corrosion so the object was now the dark grey colour of the underlying steel, however internally much more lacquer had survived allowing the original black colour to be seen on many of the components. More significantly a number of markings had also been revealed during the cleaning process;

- The interior of the left-hand side of the case, immediately above the printer socket assembly was inscribed "Chiffrier M38".
- The interior floor of the case underneath the lamp board was inscribed "CH M47".
- Externally on the underside, the base was inscribed "110".

Examination of the machine, both before and after conservation, led to the conclusion that it is one of the G31 series of machines, in addition the presence of the printer socket on the on the left-hand side, strongly suggests that it was one of the "*Zählwerk und Kupplung*" machines within this series. The third inscribed number listed above is of most significance, leading the authors to conclude that this is Machine G 110, one of the series of machines G 101-G 124 delivered to Hungary in 1931 as described earlier. If this is the case it makes this a very rare Enigma. Only one other of this type, G 111, has been identified and this remains in a private collection, leaving the Bletchley Park example as the only one on public display.

It is difficult to reach any firm conclusions concerning the wartime life of this machine or which part of the Hungarian armed forces or intelligence services used it. All that is known is that it was sold to Hungary in 1931 and found its way later to a farmyard in southern Poland. If it was in use by the Hungarian army, this location is broadly consistent with the final battlefields of the Hungarian First Army. This force was almost completely destroyed alongside the German First Panzer Army in fighting against the Soviets in January 1945 along the borders of modern Slovakia, the Czech Republic, and Poland. The deliberate disassembly of the machine and its burial are consistent with its disposal by a retreating or surrendering signals unit at that time. At present, however this narrative remains purely speculative.

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