BATTERY VOLTAGE PROBLEMS IN CROSSBAR TELEPHONE EXCHANGES

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I. Introduction

The present stage of development of automatic telephone equipment is marked by the headway the use of crossbar switches is making. Unlike friction-brush type switching equipment, with brush assemblies sliding along a straight-line or curved tracks, modern crossbar switches operate only with relay-like motions. Consequently, a substantially lower amount of power is required for the operation of this new-type switch than is needed for earlier types of equipment. Obviously, the question may be raised as to the optimum value of the operating voltage of telephone exchanges built up on crossbar switches.

This paper examines the reasons why the voltage of batteries used in manually operated telephone exchanges had to be increased from the original 24 volts to 48, or even 60 volts, on the introduction of automatic service. A survey will also be given of major considerations determining the rating of voltage.

As is known magnets and relays account for about sixty per cent of the overall costs of a telephone exchange. It is essential, therefore, that by considered assessment of the different factors a voltage value should be determined for the operation of a particular exchange, which in turn might be apt in resulting the possibly highest reduction of costs.

II. Calculation of windings

For reasons of economy relays and functional magnet assemblies should, in general, be of a size that a *minimum quantity of copper* should suffice for the generation of the required pulling force. Exception may, however, be made for cases when conditions bearing on the duration of operation, or such as are relate to a pre-determined resistance value, have been specified for the particular magnet assembly.

The operating force may be written as

$$P = \frac{\Phi^2}{2\,\mu\,F} 10^4 \text{ gr}$$

where F denotes the cross-section of iron in sq. centimetres,

μ the magnetic permeability of iron,

Φ the magnetic flux obeying the equation

$$\Phi = \frac{0 \cdot 4\ \pi\ ni}{\dfrac{l_1}{\mu F_1} + \dfrac{l_0}{\mu_0 F_0}}\ 10^{-8}\ \text{volt sec}$$

where ni is the number of field ampere turns,

l_1 the length of the iron portion of the magnetic circle in centimetres,

l_0 the length of the spark gap in centimetres,

F_0 the cross-section of the air gap in sq. centimetres, a value as a rule larger than that of F_1.

For a given type of magnet, *i. e.* for specified geometrical dimensions, Φ is the function of ni, while the value of P depends of that of $(ni)^2$. Consequently, when the winding space has been defined, a maximum number of ampere turns may be obtained by the least amount of copper, provided that the copper had been loaded with a *maximum current density*.

The current intensity obtainable in the winding may be written as follows :

$$i = i_s \frac{\delta^2 \pi}{4} 10^2\ \text{amps}$$

where i_s denotes the maximum permissible current intensity in the winding expressed in terms of amps/sq. millimetre, for windings generally employed in telephone technique, and at a continuous load of the order of 4 to 5 amps/sq. millimetre,

δ the diameter of the wire in centimetres.

Accordingly, the number of turns on a fully wound core, may be expressed as

$$n = k \frac{4\,Q}{\delta^2 \pi}$$

where Q is the cross-section of the winding space in sq. centimetres,

k a space filling factor, being the function of δ ; for wire diameters current in telephone technique, *i. e.* diameters ranging from appr. 0,08 to 0,4 millimetre, this factor, with increases in the value of δ, may become 0,45 to 0,6.

The number of ampere turns obtainable may be expressed by the following equation :

$$ni = k \frac{4\,Q}{\delta^2 \pi}\, i_s \frac{\delta^2 \pi}{4} = \text{k} \cdot Q \cdot i_s$$

Since both Q and i_s are constants, the equation is reduced to

$$ni = \text{const}\ k$$

i. e. for a definite winding space the maximum number of obtainable ampere turns *is independent of variations of the two components of ni, i. e.* the value of *ni* only increases when the value of k is sufficiently large, or, with other words, *a larger number of ampere turns can be obtained for windings made of sufficiently thick wire, i. e. windings having a lower resistance value.*

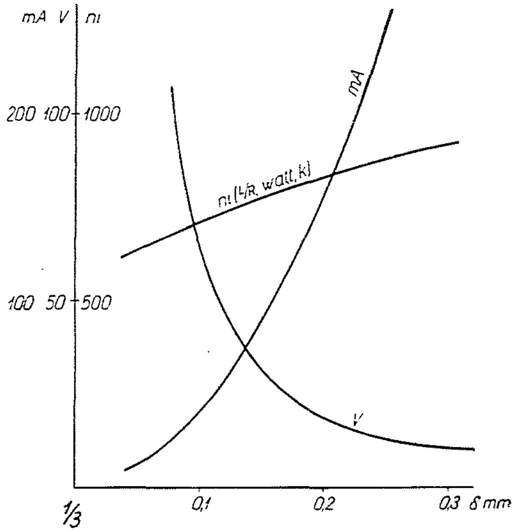

Fig. 1. The parameters of relays as functions of the diameter of coil wires

The value of the voltage required for the specified current intensity is expressed by the following equation :

$$E = i \cdot R_t \text{ volt}$$

where R_t is the resistance of the winding expressed in ohms, *i. e.*

$$R_t = i_s \frac{\delta^2 \pi}{4} k \frac{4\,Q}{\delta^2 \pi} \varrho \frac{4\,l_m}{\delta^2 \pi}$$

l_m being the average length of a single turn on a fully wound core

$$E = \text{const} \cdot \frac{k}{\delta^2} \text{ volt}$$

I. e. while the increase of the current intensity can be expressed as the square ratio of the wire diameter, the voltage drops by the inverse square ratio of the wire diameter. *This means that the power consumption increases* *with the wire diameter only insofar as the value of k increases.* Consequently, the curves of both ni and the power consumption are essentially identical with that plotted for k as a function of δ, as shown in Fig. 1.

For purposes of practical calculations certain limitations may enter the picture. Thus the current intensity possibly should not exceed a value of 0,3 to 0,5 amp. lest the point-like contacts of precious metal should rapidly deteriorate under the impact of the contact pressure of 20 to 30 grammes in general characteristic of relays, particularly at breaking inductively loaded circuits. At a continuous load the watt consumption of relays should not rise above 3,5 to 4 watts, lest the accumulated heat should have a damaging effect on the insulation of the enamelled wires.

There is a minimum size for the construction of relays, determined by the length of springs employed. Furthermore, the volume of the relay will depend on the maximum number of contacts required, and on the number of ampere turns specified for their operation. *The maximum number of contacts are the function of the circuit requirements.* The so-called flat type R relays in current use, in this country, may have as many as fourteen contact springs (*e. g.* two change-overs and four makes), the cross-section of the winding space being approximately three sq. centimetres, the volume of the winding about 12 cubic centimetres. With a relay winding of this size, and a wire diameter of 0,1 millimetre

$$ni = k \cdot Q \cdot i_s = 0{,}45 \cdot 3{,}500 = 675$$

ampere turns can be obtained, while with a thicker wire of, let us say, 0,4 millimetre in diameter, the number of ampere turns can be increased to about 900.

The number of ampere turns obtainable for each cubic centimetre of winding is of the order of 55 to 75.

Calculations show that in the previous case the resistance of the relay is 1650 ohms, the number of turns being 18 000. The voltage required for operation may be written as

$$E = \frac{ni}{n} R = 65 \text{ volts}$$

The resistance of a winding made of a 0,4 millimetre wire is 8 ohms, the number of turns being 1400, so that for 900 ampere turns a voltage of

$$E = \frac{900}{1400} 8 = 5.2 \text{ volts}$$

will have to be specified.

In this latter case current intensity takes on a too large value. If the current intensity is limited to *e. g. 0,1 amp*, then in order to ensure a current density of 5 amps per sq. millimetre the wire diameter will have to be

$$\delta = 0{,}16 \text{ millimetre}$$

With a wire of this diameter the resistance of the realizable winding will be 285 ohms, and the number of turns 7800. The maximum number of ampere turns obtainable reads

$$ni = 780$$

and the voltage required

$$E = \frac{780}{7800} 285 = 28 \text{ volts}$$

(The consumption of the relay is 2,8 watts.)

For all practical purposes, with now current designs 200 to 250 ampere turns generally suffice for the operation of the fourteen contact springs, mentioned earlier in this section. When no operating time has been specified, with a reasonable margin of safety 300 ampere turns have to be provided for the operation of the relay, so that a voltage of less than 28 volts will suffice.

As a matter of course relays used in more complex circuits may operate in a number of combinations, and therefore they may have to be provided with two, or even more, windings. On the other hand, in the majority of cases the number of contact springs to be provided for relays is substantially below fourteen. However, in equipment using crossbar switches at several places, *e. g.* for the connection of the common marker circuits, relays with a large number of make contacts may be required. The design of these types of relays can by no means be identical with that of the active relays of the circuits, although the magnetic pull force in this type of relays may on hand of the formula derived earlier in this action be even 1000 grammes, provided that soft-iron of satisfactory quality has been used. This force is appropriate for the operation of twenty to twenty five make contacts.

The battery of the exchange will have to be designed for the supply of a voltage at which *the relays may in a satisfactory manner assist in the solution of the overwhelming majority of circuit problems*. Obviously, in particular cases two relays may have to be employed for the solution of certain specific problems. For reasons of economy the design of the relay will have to be adapted to *conditions most frequently encountered.*

The preceding calculations tend to confirm that even with current types of relays the number of ampere turns most frequently satisfying recurring requirements may be accomplished *with voltages below 48 volts.* It was not due to relays that in automatic exchanges the voltage had to be raised to values above 24 volts, the usual value for manual equipment.

In practice for a large percentage of relays the number of contacts may be less than that of the maximum carrying capacity specified for the particular relay. Consequently, a lower number of ampere turns will suffice and with the customary thin wires the resistance needed will not be ensured at a given voltage. In this case part of the winding may have to be replaced by *resistance wire. The larger the battery voltage* than the voltage value at which the majority of relays is realizable without the substitution of resistance wire, *the larger the number of relays* for which at an increasing rate *resistance wire will have to be used.* Obviously, this condition will add to the costs of relays.

Stepping or switching magnets may occasionally have to exercise a substantially larger pull force than relays. In this case a larger winding volume is required to ensure an appropriate number of ampere turns. In the Strowger system, and other similar systems operating on the step-by-step principle, the size of the windings is determined by requirements set by the operating time rather than by other conditions. In systems operating with crossbar switches the magnets will have to overcome the resistance of the springs, and the pull force to accomplish this does not in general exceed the values obtainable with windings of a size of those of the relay type. However, here the time factor may enter into the picture, and substantiate the use of larger voltage.

III. Operation time

The electrical portion of the actuating time of a relay, *i. e.* the time lapsing before the armature starts, may be written as

$$t = \frac{L_t}{R_t} \ln \frac{1}{1 - {}^{I_m}/_{I_0}} \text{ sec}$$

where L_t/R_t is the time constant of the winding,

I_m the setting current intensity at which the armature starts,

I_0 the definitive current intensity resulting from the ohmic law.

The value of the time constant may be expressed as

$$L_t = \frac{0{,}4\,\pi\, n^2}{\dfrac{l_1}{\mu_1 F_1} + \dfrac{l_0}{\mu_0 F_0}}\, 10^{-8} \text{ henry}$$

and for a given design as

$$L_t = \text{const} \cdot n^2 \text{ henry}$$

$$L_t/R_t = \text{const} \left(\frac{4 \cdot k \cdot Q}{\delta^2 \pi}\right)^2 \frac{(\delta^2 \pi)^2}{16 \cdot k \cdot Q \cdot \varrho \cdot l_m} = \text{const}\, \frac{k \cdot Q}{l_m\, \varrho} = \text{const}\, k$$

This means that time constant L_t/R_t is the function only of the space filling factor *k*. Essentially the actuating time depends on the second part of the equation, *viz*.

$$\ln \frac{1}{1 - \frac{I_m}{I_0}}$$

The value of this formula is a function of the relation of I_m/I_o. If

$$I_m/I_0 \longrightarrow 0 \quad \text{then} \quad t = 0$$

and

$$I_m/I_0 \longrightarrow 1 \quad \text{then} \quad t = \infty$$

In the formula of the actuating time the expression *ln* is essentially a multiplier. In practice for reasons of safe functioning

$$I_{m\,\max} = 0{,}8\, I_0$$

On the other hand the minimum is determined by a ratio of the minimum number of ampere turns required for the operation of a single make-contact.

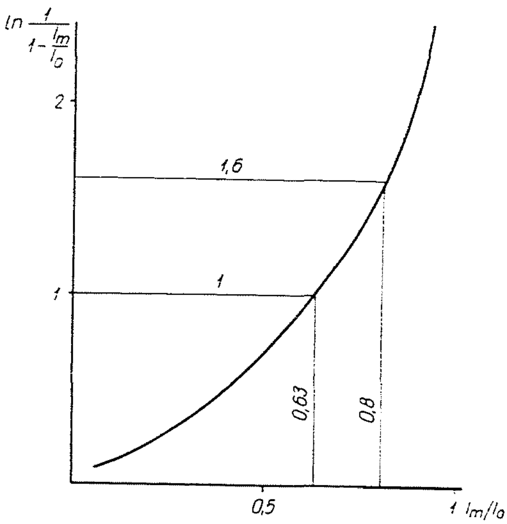

Fig. 2. Operating time increase of relays as a function of their adjustment current intensity

and the maximum possible number of ampere turns. The 70 to 80 ampere turns required for a make-contact represent approximately ten per cent of the maximum number of turns obtainable. In practice, therefore, the value of the multiplier may vary between

$$\ln \frac{1}{1-0.8} = 1{,}6$$

and

$$\ln \frac{1}{1-0.1} = 0{,}1$$

This variation expressed as a function of I_m/I_o is shown in Fig. 2. The value of the multiplier will become the unity, *i. e.* the time constant will remain the sole factor influencing the actuating time, when I_m becomes about 63 per cent of I_0.

Inasmuch as for a given winding space time constant L_t/R_t essentially varies with the space filling factor only, and is lower for thin wires, the only feasible scheme for shortening the actuating time is *to increase the value of* I_o, I_m being of a definite value owing to the function to be performed by the magnet. *This is the reason that entailed the necessity of increasing the voltage.* It was on this principle that the windings of the Strowger system of 60 volts 60 ohms, causing the brush assemblies of the selectors to step with a power consumption of 60 watts, had been developed. Owing to the known properties of the Strowger system it was essential to ensure high-speed operation of the equipment. (Direct actuation in response to the dial pulses, free selection of limited duration between two digits, etc.). Magnets of this type are encumbered with a number of disadvantages, *e. g.* fire risk, interruptions of the current of one ampere equalling to heavy strains on the contacts, strong shocks causing noises towards the battery, complications involved in spark quenching, etc.

Owing to the use of registers, conditions in the Rotary system are by far more favourable. When a 48 volt battery is used, 10 watt windings amply suffice for the operation of switching magnets. Improvements in the operating conditions of exchange equipment using crossbar switches are still more remarkable. Here time-conditioned, high-speed magnets can be dispensed with. The number of ampere turns required for operation may be accomplished with voltages below 48 volts.

Since the size of relays, and in case of crossbar exchanges, of the magnets actuating the bars, does not even require 48 volts, less the 60 volts, certain other considerations will have to be examined which may have a bearing on the battery voltage.

IV. Other considerations

1. *Problems of the feeding bridge*

In order to ensure an adequate microphone current, even for long lines, the ohmic resistance of the feeding circuit has to be kept as low as possible, or in other words, the resistance of the feeding bridge determines the maximum permissible resistance of a subscriber's loop. The impedance of the feeding bridge has to be large enough to check the speech currents. Furthermore the feeding bridge has to be free of fire risk, even under the most rigorous conditions.

Fig. 3 shows the standard feeding bridge of the 7A2 Rotary equipment. The high impedance is ensured by a separate choke coil, the signalling relay being of the usual flat type. The figure shows the values of the ohmic resistance for a 48-volt battery. Calculations indicate that pure earth leakage on wire "*b*" will cause a consumption of 5,5 watts only in the relay.

For microphones now in use a minimum current intensity of 0,030 amp. is required. The upper limit is of no particular interest, partly because even for a 0-ohm loop the intensity will fail to reach the dangerous value of 0,1 amp., partly because modern telephone apparatus are provided with current limiting features.

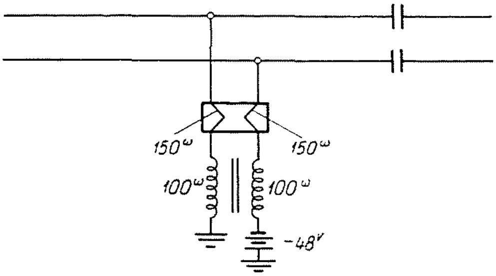

Fig. 3. 7 A2 type feeding bridge

The microphone current of 0,030 amp. permits the following loop resistance maxima, provided that the resistance of the supply relays has been determined so as to keep *the watt consumption of the relays permanently on a level of 5,5 watts*

Battery voltage	Resistance of the feeder bridge	Max. loop resistance
24 volts	2 × (40 + 25)	670
36 volts	2 × (90 + 60)	900
48 volts	2 × (150 + 100)	1100
60 volts	2 × (240 + 160)	1200

With the increase of the number of telephone exchanges the average length of subscriber's loops is gradually decreasing. Since for reasons of stress it is unlikely that diameters below 0,4 millimetre should be chosen for wires, a loop of 1100 ohms represents a *distance of about 3,5 kilometres.* This length appears to be satisfactory, inasmuch as the upper limit of 0,45 N for the attenuation specified by CCITT is reached sooner than the loop resistance of 1100 ohms.

Consequently, as far as feeder bridges are concerned *the 48-volt battery appears to be satisfactory* and the 60-volt battery affords no particular advantages against the 48-volt type, not even on this count.

2. *Sparking*

The value of the voltage arising at opening an inductively loaded contact may be written as

$$E_s = -L\frac{di}{dt}.$$

Assuming a relay to perform a definite task and an identical *upper limit* for the consumption at varying voltages, the current flowing in a 60-volt relay will have to be by 20 per cent below that flowing in a 48-volt relay. On the other hand, to ensure a satisfactory pull force, or an appropriate number of ampere turns, for a 60-volt battery the number of turns will have to be increased by the same percentage.

While the value of di/dt will slightly decrease (however, not linearly, as the current disappearing period dt decreases almost linearly) with the current intensity, the self-induction will increase proportionally to the value of n^2, if a 60-volt battery is used. At identical operating conditions, therefore, *sparking will become more intense in case of a higher battery voltage.*

Note that in inductively loaded circuits the potential drop across the condensers will increase linearly with the battery voltage, *e. g.* when spark quenchers are used. Consequently, when condensers of the same make are used the safety factor, too, will drop by about twenty per cent, when the battery voltage is 60 volts.

3. *Battery and busbars*

As far as storage batteries and battery chargers are concerned the battery voltage has but little to say. The costs of the power supply plant represent a low percentage only of the overall costs of telephone equipment. Accordingly, slight fluctuations of prices, in one sense or the other, are for all practical purposes negligible. For 60 volts a larger number of cells may be required, while for 48 volts the dimensions of the cells may be larger.

Busbars are in general dimensioned so as to make allowance for a certain voltage drop of let us say one per cent at the maximum load. Accordingly, provided the watt consumption remains identical, when a 60-volt battery is installed instead of the 48-volt, current intensity will drop by 20 per cent, and the cross-section of the copper bar by a further 20 per cent, making a total of 36 per cent. However, this reduction of weight will at the usual battery-equipment distances amount to *not more than 100 to 120 kilogrammes* for two busbars and for a 10 000-line city exchange. Copper requirements for an exchange of this size amount to about *20 000 kilogrammes* approximately, one third whereof being accounted for by the windings. The amount of copper converted into busbars is too insignificant as compared with the total quantity of copper absorbed by the exchange.

4. *References*

The fact that the majority of crossbar exchanges operated all over the world uses 48-volt batteries, *e. g.* in the USA, cannot be ignored. If 60-volt batteries gave any particular advantages, it may be taken for granted that 60-volt batteries would have been adopted for the Panel System, instead of the 48-volt type, the more so as 60-volt batteries are employed in Strowger equipment from the earliest date. Notwithstanding this fact, the 48-volt battery continues to be in use in the various types of crossbar equipment.

Ericsson crossbar exchanges are in general operated from 48-volt batteries, and only in exceptional cases designing engineers deferred to particular wishes expressed by certain administrations, *e. g.* in Finland, where the crossbar exchange was designed for operation from 60-volt batteries.

V. Conclusions

The logical conclusion, from what has been set forth in this paper, is that in crossbar equipment 48-volt batteries have certain *definite advantages* as compared with 60-volt batteries. In the Strowger System *the use of 60-volt batteries was necessitated* by the step-by-step type operating magnets, rather than by any specific advantages of the 60 volts.

It would be an exaggeration to state as if the problem of voltage were a determining factor in the cost estimates of an exchange. On the other hand, no conclusive reasons may be cited substantiating the use of higher voltages.

The entire problem of voltage may have to be considered from altogether different aspects, when *electronic elements* will be introduced in the control system of crossbar exchanges. Then the necessity may arise of various power supply systems, and the magnets of the contact field may have to be made subject to the requirements of the controlling elements. However, as long as predominantly electromagnetic devices are used for controlling purposes, and other, *e. g.* not technical considerations, do not influence the decision of the designing engineer on the question of battery voltage, it is beyond doubt that 48-volt batteries will win the day against the 60-volt type.

Summary

In development work of crossbar telephone exchanges the problem of the operating battery voltage for this type of equipment is considered. The paper gives a survey of some of the aspects which may have a bearing on the ultimate decision in the matter of voltage, and on hand of a number of points considered concludes in favour of the 48-volt battery.

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