GER-2622A

MULTILIN

GE Power Management

Synchronism Check Equipment

SYNCHRONISM CHECK EQUIPMENT

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INTRODUCTION

Synchronism check equipment is that kind of equipment that is used to check whether or not two parts of the same system or two separate systems are in synchronism with each other. The equipment covered by this paper is of two classes. The first is comprised of standard speed devices (Type IJS) that will check the presence of synchronism in a matter of several seconds and then produce an output to permit closing or reclosing the associated breaker if synchronism exists. The second class is a high-speed device (Type GXS) that operates in the order of one second to check synchronism. In both cases, it is important to recognize that synchronism check devices are basically permissive devices in that they permit or prevent closing that is initiated by some other device. Synchronism check devices *do not* initiate reclosing.

When deciding to select either the standard or the high-speed device, the user should be aware that all synchronism check relays can be fooled by a condition where the slip between the two systems being checked is slow enough to appear in the relay characteristic long enough to produce an output. In general, the slower the relay, the slower the slip required to fool the relay. Thus, the GXS device could be more subject to this problem than the IJS device. This is discussed in detail in subsequent sections of this paper and should be considered carefully before making a selection.

Both types of synchronism check equipments require single-phase (line-to-line or line-to-neutral) potentials from the same phase(s) on both sides of the associated circuit breaker or the equivalent thereof in the case where a delta-wye power transformer is interposed between the two sources of potential.

GENERAL

There are two kinds of synchronism check equipment available. The first, and by far the most prevalent, is the slow-speed device Type IJS. The second, and not so prevalent, is the high-speed device Type GXS. The high-speed synchronism check relay (GXS) finds application primarily in conjunction with high-speed automatic reclosing, but it may be employed whenever high-speed synchronism check with a lock-out feature is desired. The slow-speed device (IJS) is used to supervise manual local, and/or supervisory closing, and/or time delayed automatic reclosing where the possibility of the lack of synchronism exists.

OPERATING PRINCIPLES OF IJS

The IJS relay is an induction disk device that receives single-phase voltages from the same phase(s) on both sides of the breaker. There are two electromagnets in the relay, and each electromagnet has two coils. In the first, or operating electromagnet, the coils are connected in such a way that they receive the vector sum of the two voltages (incoming V_i and running V_r). This electromagnet produces a torque on the disk in the direction to *close* the relay contacts. This operating torque is proportional to the square of the vector sum of the two voltages as indicated in Equation (1).

$$T_{op} = K_{op} (V_i + V_r)^2 \qquad \text{Equation (1)}$$

where K_{op} is a design constant.

The second electromagnet is the restraining device. It receives the vector *difference* of the incoming and running voltages from the same phase (s). This electromagnet acts on the same disk as the operating magnet, but it produces torque in the opposite or restraining direction. That is, it develops torque that tends to hold the relay contacts *open*. This restraining torque is proportional to the square of the vector difference of the two voltages as given by Equation (2).

$$T_r = K_r (V_i - V_r)^2 \qquad \text{Equation (2)}$$

where K_r is a design constant.

In addition to the electrical torques in the relay, there is also a mechanical restraint in the form of the control spring. Thus, the net torque operating torque (T) in the relay is the result of all three.

$$T = K_{op} (V_i + V_r)^2 - K_r (V_i - V_r)^2 - K_s$$

In general, the mechanical restraint (Ks) is small compared to the electrical torques so that the above equation becomes

$$T = K_{op} (V_i + V_r)^2 - K_r (V_i - V_r)^2 \qquad \text{Equation (3)}$$

It should be noted that with equal voltages on the running and incoming busses, $(V_i + V_r)$ will be equal to $(V_i - V_r)$ when V_i and V_r are 90 degrees apart. As the two voltages approach each other in phase angle, $(V_i + V_r)$ will become greater than $(V_i - V_r)$ and vice versa. Thus, the net operating torque tends to increase as the two systems tend to be more in phase with each other. Whether the net torque is in the operating direction ($T>0$) or in the restraining direction ($T<0$) will also depend on the relative magnitudes of K_{op} and K_r. In the case of all the IJS relays, K_r is designed to be greater than K_{op} so that the net torque goes from restraining to operating at some angular separation that is smaller than 90 degrees. This angle is called the *closing angle*. Some IJS relays have fixed closing angles while others have closing angles that are adjustable.

The operating time of the IJS is determined by two factors, one of which is the strength and position of the permanent drag magnet that acts on the disk to slow its motion, and the other is the rotary distance that the disk has to travel to close the contacts. The former is a built-in characteristic that differs from model to model, and is not adjustable in the field, while the latter is adjustable and depends on the time dial setting applied to the relay.

Since K_r is greater than K_{op}, if only one voltage (V_r or V_i) is applied to the relay the torque T will be negative and the relay contacts will be held open. This is apparent from Equation (3). With neither voltage applied, the net electrical torque is zero, but the *spring* will keep the contacts of the relay open. Thus, in order for the IJS relay to close its contacts, there must be voltage present on both sides of the open breaker, and the phase angle between these voltages must be within the closing angle setting of the relay. This means that the synchronism check unit by itself will not permit picking up a dead line. For applications where dead line and/or dead bus operation is required, undervoltage detectors are used to bypass the synchronism check device. Some models of the IJS include these dead line and dead bus auxiliary devices, while others do not.

OPERATING CHARACTERISTICS OF IJS

As indicated above, there are several different models of IJS relays. The most popular standard models are listed in Table I along with information relating to the differences between models. While Table I lists only 115-volt 60-Hz relays, models for operation at other voltages and frequencies can be made available on request.

All the IJS relays covered by Table I come completely self-contained in a size S1 case. The outline dimensions for this case are given on Fig. 1.

TABLE I

RELAY MODEL	Ratings Δ VOLTS	FREQ	CLOSING ANGLES AT RATED VOLTS	TARGET SEAL-IN	CASE SIZE	DEAD-LINE - DEAD-BUS AUXILIARIES	EXTERNAL CONNS	INTERNAL CONNS	APPLICABLE CHARACTERISTICS
IJS51A1A	115	60	20 degrees*	0.2/2.0 amps	S1	None	KW-121967	K-6305898	K6400151, 165A7535 0208A2315
IJS51A3A	115	60	20-60 degrees	0.2/2.0 amps	S1	None			376A964, 165A7535 0208A2314
IJS52A1A	115	60	20 degrees*	None	S1	None	KW-122067	K-6400419	K6400151, 165A7535 0208A2315
IJS52A7A	115	60	20-60 degrees	None	S1	None			376A964, 165A7535 0208A2314
IJS52D1A	115	60	20 degrees*	None	S1	Instantaneous Operation**	KW-121867	165A6040	K6400151, 165A7535 0208A2315
IJS52D3A	115	60	20-60 degrees	None	S1	Instantaneous Operation**			376A964, 165A7535 0208A2314
IJS52E1A	115	60	20 degrees*	None	S1	Time delay Operation**	KW-121267	165A7608	K6400151, 165A7535 0208A2315
IJS52E3A	115	60	20-60 degrees	None	S1	Time delay Operation**			376A964, 165A7535 0208A2314

Δ Other voltages and frequency ratings can be made available on request

* Actually adjustable 20 to 60 degrees, but not recommended

** See Application Section for more information

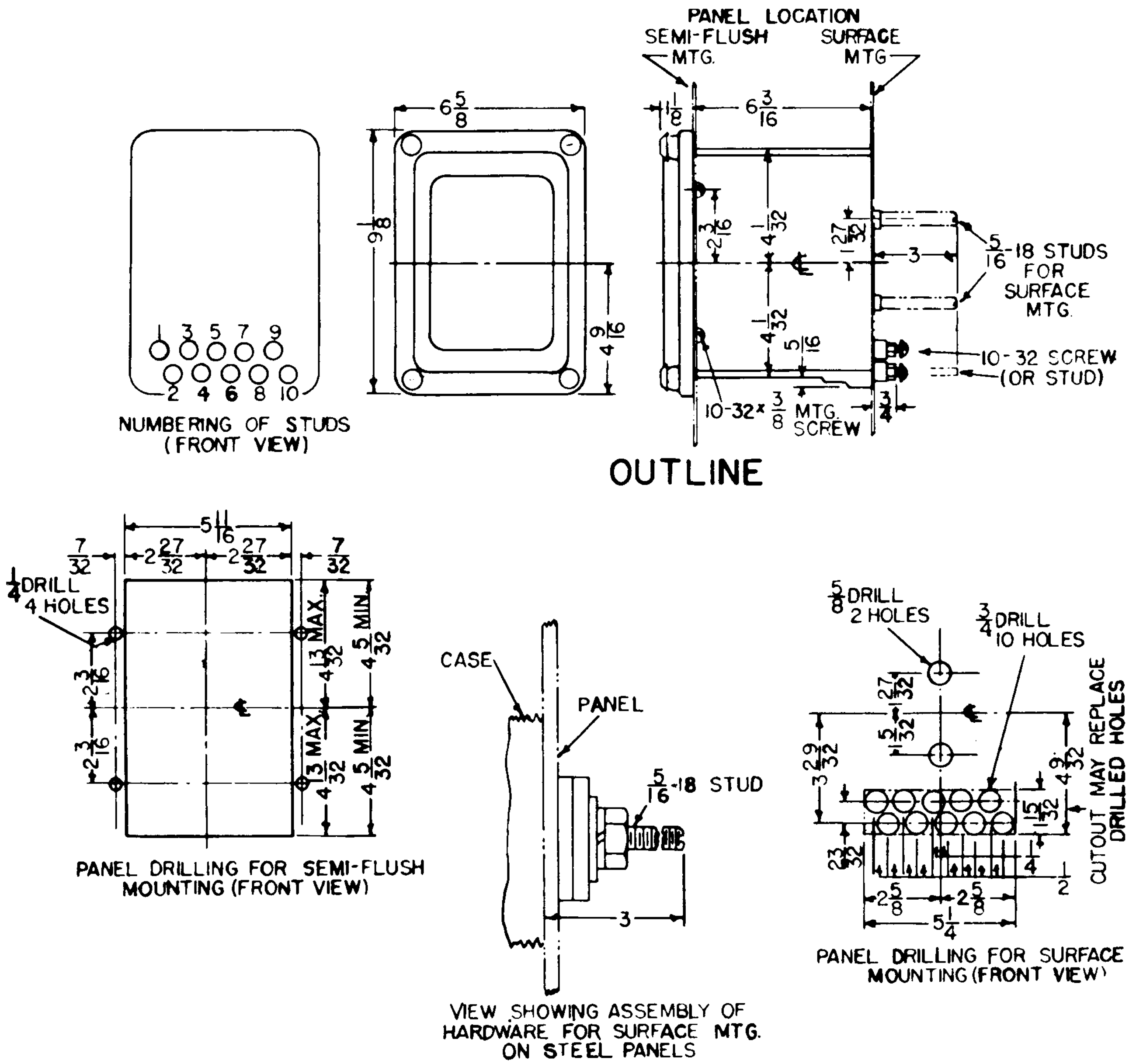


Fig. 1. Outline and panel drilling for drawout relays, size S1. (K-6209271)

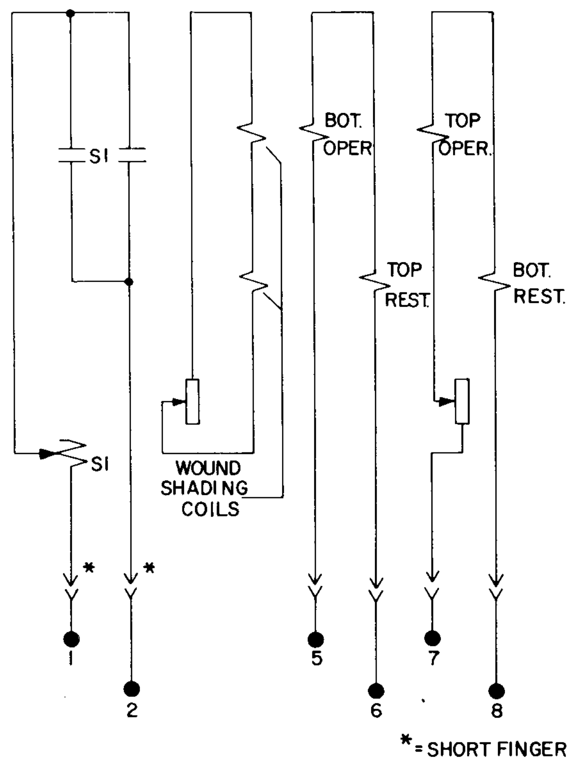


Fig. 2. Internal connections for IJS51A. (K-6305898)

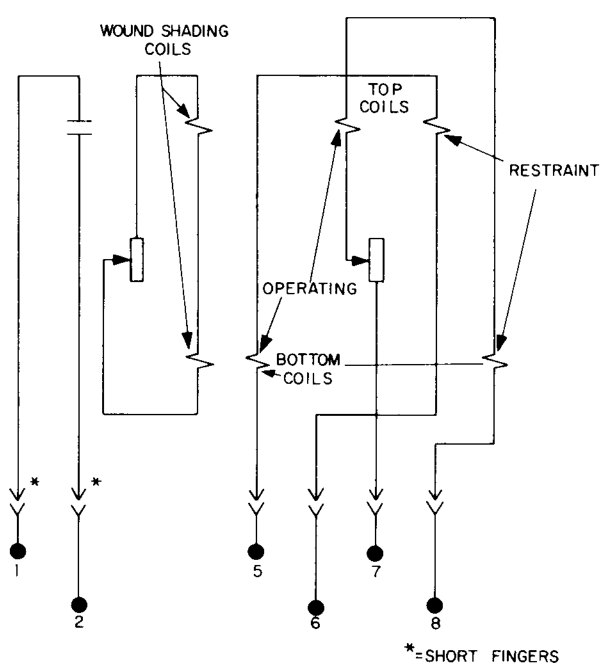


Fig. 3. Internal connections for IJS52A. (K-6400419)

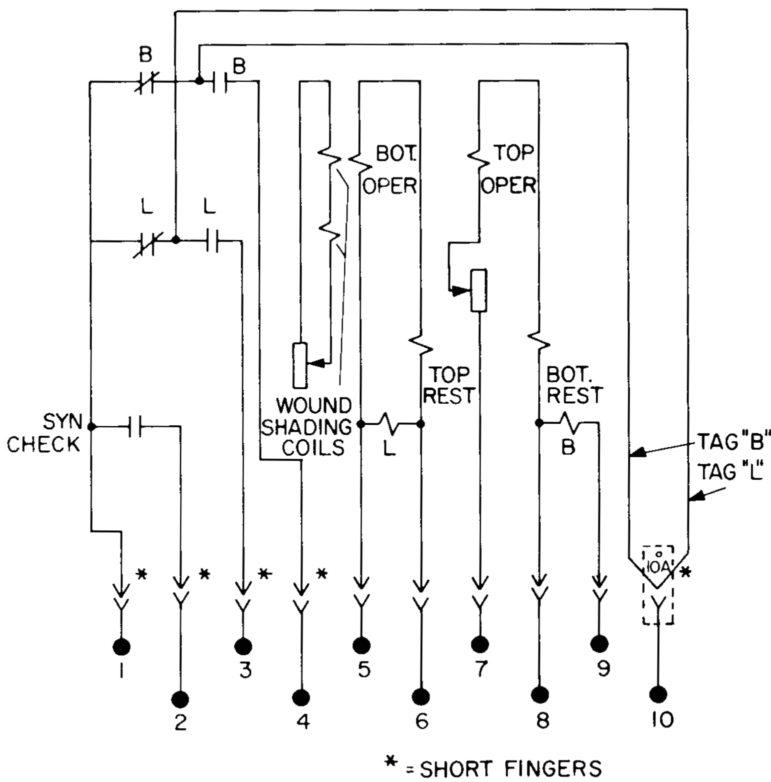


Fig. 4. Internal connections for IJS52D. (0165A6040)

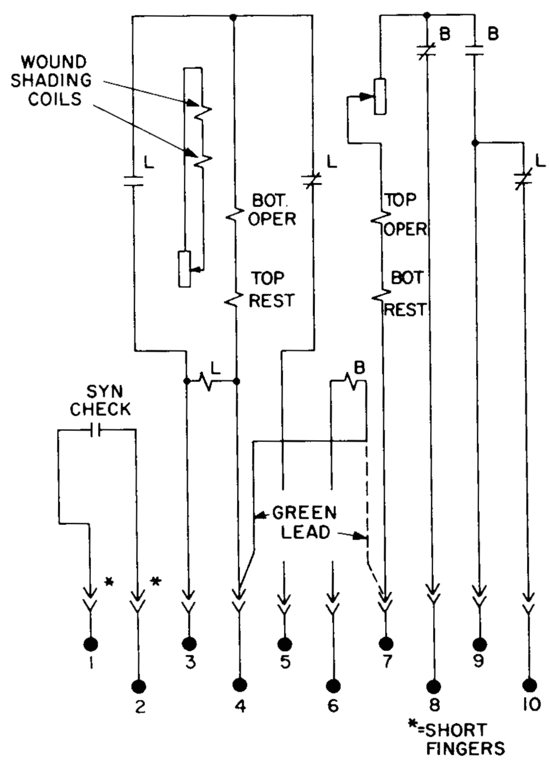


Fig. 5. Internal connections for IJS52E. (0165A7608)

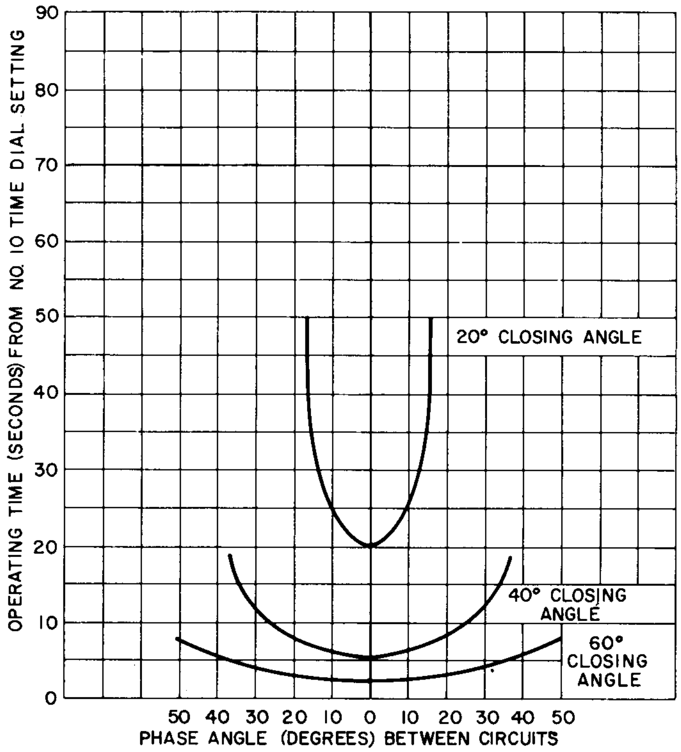


Fig. 6. Operating time as a function of closing angle setting and phase angle between incoming and running voltages. Applies to Models IJS51A1A, IJS52A1A, IJS52D1A, and IJS52E1A. (K-6400151)

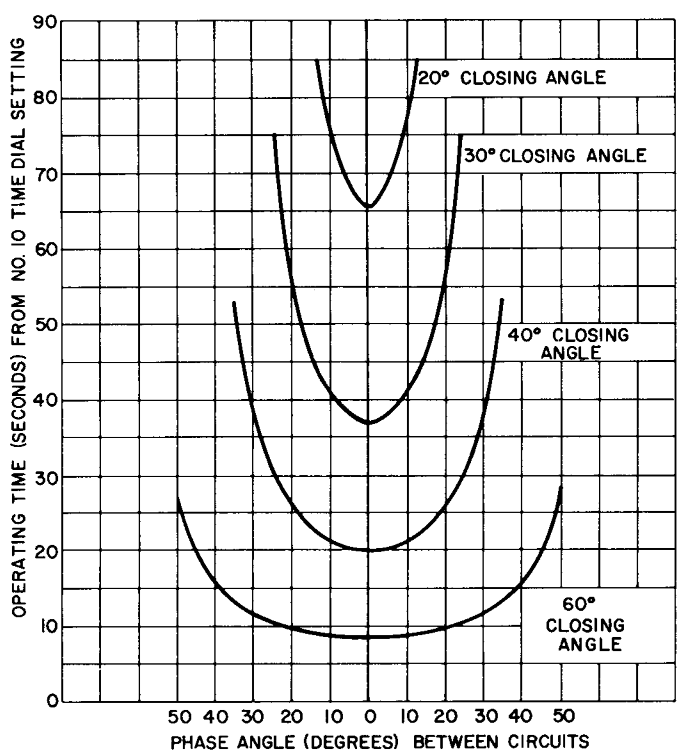


Fig. 7. Operating time as a function of closing angle setting and phase angle between incoming and running voltages. Applies to IJS51A3A, IJS52A7A, IJS52D3A, and IJS52E3A. (376A964)

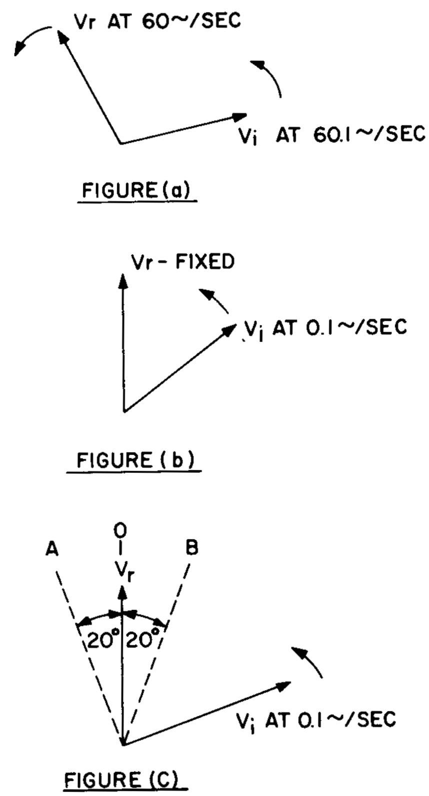


Fig. 8. Vector relationships between "running" (V_r) and "incoming" systems. (KW-122167)

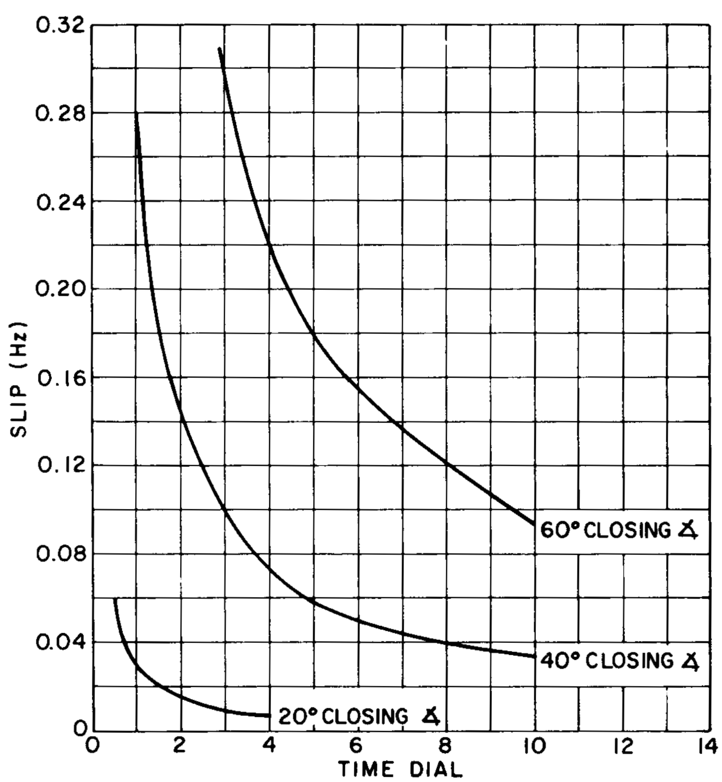


Fig. 9. Maximum slip for which the relay will permit closing as a function of time dial setting and closing angle setting. Applies to IJS51A1A, IJS52A1A, IJS52D1A, and IJS52E1A. (0208A2315)

As may be noted from Fig. 2 (IJS51A), Fig. 3 (IJS52A), and Table I, the only difference between the IJS51A and the IJS52A relays is that the IJS51A contains a target seal-in unit while the IJS52A does not. Neither model contains any dead-line or dead-bus voltage detecting devices. However, both the IJS52D and IJS52E models do include these devices, but the manner in which these undervoltage detectors are internally connected differ between the two models. These differences can be observed by referring to Fig. 4 (IJS52D) and Fig. 5 (IJS52E). The contacts available on the voltage units in both relays permit a number of variations of dead-line and/or dead-bus operation. In the case of the IJS52D, this operation will be instantaneous, but in the IJD52E, the undervoltage units are interlocked with the synchronism check unit so that time delay operation is obtained in dead-line - dead-bus schemes. This will be covered in detail under the section on APPLICATION.

The fourth column in Table I indicates the closing angles of the relays listed. There are only two different kinds: one that is fixed at 20 degrees; and another that is adjustable in the range of 20 to 60 degrees. The only difference between the two types is that the drag magnet in the 20 to 60 degree relay is stronger, so that the operating time for a 20-degree setting is longer than it is for the 20-degree unit. Actually, the 20-degree relay can be set for greater closing angles; however, it is not generally recommended because the pick-up time decreases below what might be desirable values. Figure 6 gives the operating times of the 20-degree unit (IJS51A1A, IJS52A1A, IJS52D1A, and IJS52E1A) as a function of the phase angle between two suddenly applied rated voltages. Figure 7 provides this same information for the 20 to 60 degree unit (IJS51A3A, IJS52A7A, IJS52D3A, and IJS52E3A). Note that both sets of curves apply for a No. 10 time dial setting. For lower time dial settings, the operating times will be approximately proportionally lower. For example, at a No. 5 time dial setting, the operating times will be approximately half of the values given in the curves.

When considering the characteristics of the IJS synchronism check units it is important to recognize that these units can close their contacts even when the two voltages applied are not in synchronism. The reason for this can be understood by referring to Fig. 8. Assume that the "Running" system is at 60 Hz but that the "incoming" system is at some slightly higher frequency, say 60.1 Hz. Thus, the vector V_r is rotating 60 times a second and V_i is rotating 60.1 times a second, as indicated in Fig. 8a. Since it is the relative positions of the two vectors that count, assume that the V_r vector is standing still and V_i is rotating at one revolution every 10 seconds as indicated in Fig. 8b.

If the IJS synchronism check unit, set for a closing angle of 30 degrees, is connected to these two voltages, the unit will develop closing torque when V_i lies between A and B in Fig. 8c. As V_i rotates, it enters this region at B moving counterclockwise. At that instant, the torque on the disk becomes positive (operating torque) and the disk starts to turn in the contact-closing direction. All the while that the V_i lies between A and B the torque will be in the closing direction, increasing in magnitude as V_i approaches 0 and then decreasing to zero as it approaches A. Whether or not the contacts of the unit actually close during that time will depend on the operating time of the unit (time dial setting and drag magnet strength) and the length of time that V_i is in the operating region. This latter condition depends on the difference in frequency (slip) between the two voltages and the closing angle setting of the unit. It is obvious that the bigger the angular setting and the slower the slip, the better is the chance for undesired operation. It should be noted that since the closing angle of the relay will always be less than 90 degrees, as V_i rotates at constant speed opening torque will be present for a longer time than closing torque for each revolution. This ensures that the disk is completely reset each revolution.

In the ultimate selection of a relay and a setting there must be a compromise between speed of operation and security against undesired closing operation. The curves on Fig. 9 give the maximum slip for which the IJS51A, IJS52A1A, IJS52D1A, and IJS52E1A relays will close their contacts as a function of time dial setting for closing angle settings of 20, 40, and 60 degrees. Figure 10 provides the same information for the IJS51A3A, IJS52A7A, IJS52D3A, and IJS52E3A.

Figure 11 applies to all the relays in Table I. It gives data on how the closing angle of these relays will change when the voltages applied are both not rated values. The data is based on the assumption that rated voltage is applied to one coil of the relay, while the other coil is supplied with a voltage that is other than rated. This is done for closing angle settings from 20 to 60 degrees in 10-degree steps. For example, the uppermost curve applies for a 20-degree relay setting, while the lowest one applies for a 60-degree setting.

Consider a relay set for a 30-degree closing angle at rated voltage. Checking the second curve from the top it will be noted that the contacts will close at rated voltage (115 volts) applied to both coil circuits when the angles are within plus or minus 30 degrees. Now if one voltage is reduced to about 82 volts, the unit will close its contacts only when the angle is between plus and minus 20 degrees. If one voltage is reduced to 70 volts, the relay will not operate at any angular separation. For a 20-degree setting, the relay will not operate below approximately 88 volts on one of the coil circuits. If a 10-degree setting were used, the voltage limitation would be still more restrictive. Thus, the range of voltages that may be present at the relay should be carefully considered when determining a relay setting.

As described previously, the IJS52D and IJS52E relays include instantaneous dead-line and dead-bus detecting units. These units are all alike. They are not adjustable, but they are tested in the factory to ensure that they pick up somewhere between 30 and 46 percent of rated voltage, and drop-out somewhere in the range of 14 to 31 percent.

APPLICATION OF IJS RELAYS

The synchronism check relays Type IJS find application wherever slow-speed synchronism check for automatic or manual closing of a line terminal is required.

When a transmission line is de-energized for any reason and it is to be restored to service via synchronism check, it is necessary to first close one end. This energizes the line and permits the synchronism check relay to supervise closing of the second end. It is apparent that there is no need for synchronism check at the first end to close, so closing at that end may be completely unsupervised or it may be supervised by some combination of line and bus voltage indication.

In many instances, either end of the line may be closed first. This requires that synchronism check devices be present to supervise closing at both ends of the line. Since the synchronism check relay requires an energized line in order to operate, it will block all attempts to close the first end unless it is by-passed by some other device. The by-passing function could be any one or more of a number of combinations, such as dead-line - live-bus, or dead-bus - live-line, etc.

The IJS52D and IJS52E relays include instantaneous voltage units that are connected to receive bus and line potentials. Figure 12

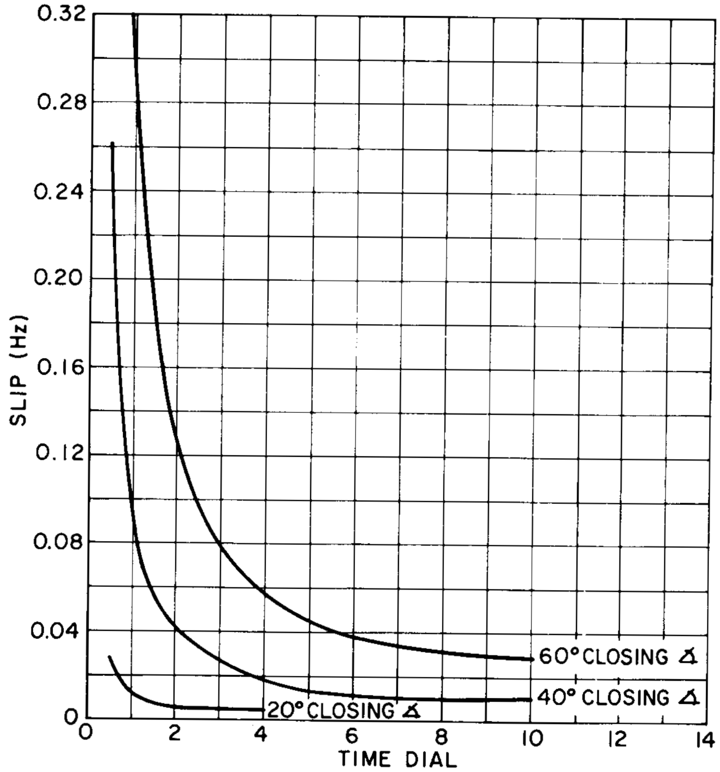


Fig. 10. Maximum slip for which the relay will permit closing as a function of time dial setting and closing angle setting. Applies to IJS51A3A, IJS52A7A, IJS52D3A, and IJS52E3A. (0208A2314)

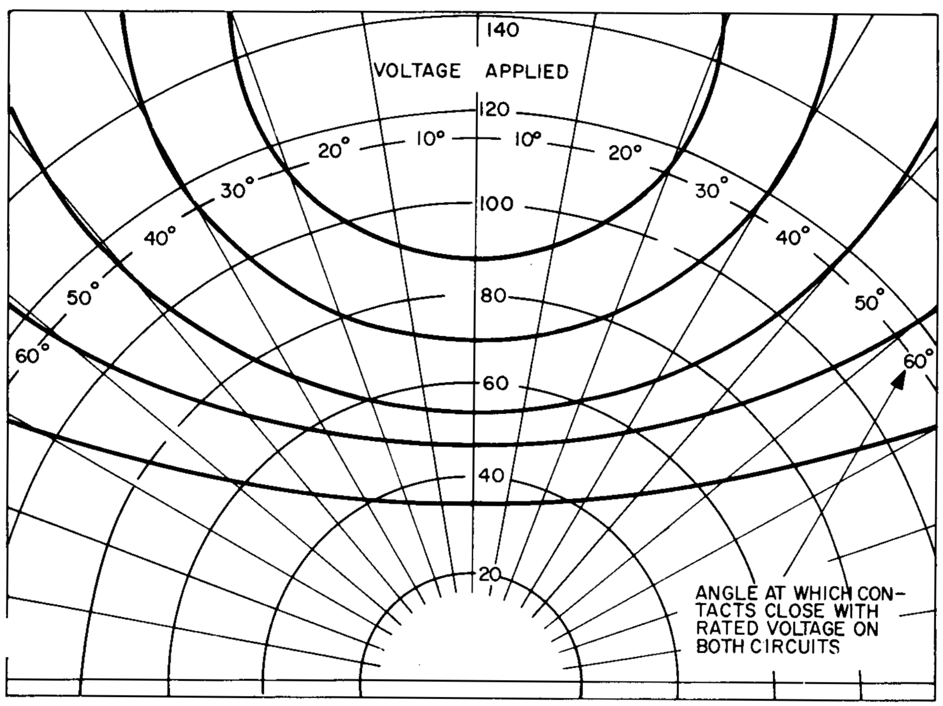


Fig. 11. Variation in closing angle as a function of applied voltage. Assumes rated voltage applied to one set of coils while the other set of coils is supplied with a voltage other than rated. Applies to all IJS relays covered by this publication. (0165A7535)

shows a typical external connection diagram for the IJS52D in a scheme that offers instantaneous voltage units in conjunction with time delay synchronism check.

This diagram illustrates how a typical selector switch may be employed to obtain a variety of schemes. In general, whether any switch is employed or not depends on the individual user's requirements. In any case, the dead-line and/or dead-bus relay contacts are in parallel with the synchronism check unit contacts. With this arrangement, the first end of the line to close will be via the voltage units. The second end will be via the synchronism check unit.

When applying such a scheme with automatic reclosing, it is important to recognize that only one end of the line should be permitted to close via the voltage units; otherwise, it would be possible for both ends to close simultaneously on, say, dead-line - live-bus when the two parts of the system are out of synchronism.

Figure 13 illustrates typical external connections for an arrangement employing the IJS52E relay. This scheme provides instantaneous dead-line and/or dead-bus detection as well as synchronism check. However, the voltage unit's contacts do not by-pass the synchronism check unit directly, but rather they switch that unit's coil circuits to live potentials so as to utilize the time delay operation of this unit. In this way, the dead-line - dead-bus closing is delayed by the operating time of the synchronism check unit.

Here too, a selector switch may be used to obtain flexibility. However, when using this scheme with automatic reclosing, only one end of the line should be permitted to close via voltage indication, otherwise, it would be possible for both ends to close simultaneously on say a dead-line - live-bus condition.

In some applications voltage units may not be required, or some sort of adjustable characteristic may be desired. For such cases, the IJS51A and IJS52A relays are available. Figures 14 and 15 illustrate how these relays would be connected when dead-line - dead-bus voltage detectors are not required. It should be noted that the only difference between the two devices is the target seal-in unit that is included in the IJS51A but not included in the IJS52A.

If external voltage relays are to be used with either of these two devices, they may be employed in a manner similar to those used in the IJS52D and IJS52E as illustrated on Fig. 12 and Fig. 13.

The 52/b switch shown in the potential circuits is required to prevent wear as a result of vibration that would otherwise occur over long periods when the associated breaker is closed and both incoming and running potentials are in phase. When required, this 52/b contact may be replaced by contacts of the closing initiation device so that the IJS does not start to operate until "requested" to do so.

When using voltage relays in conjunction with synchronism check schemes, it is important to recognize that lines with shunt reactors will maintain substantial voltages (generally at frequencies below rated frequency) for some seconds after the associated circuit breakers are open. This can affect the operation of the voltage units. Also, in some cases, due to electromagnetic or static coupling between adjacent live circuits and the dead line, voltage on the "dead" line may be present on a steady-state basis. While this voltage is generally low, magnitudes as high as 10 to 15 percent have been reported.

When selecting a synchronism check relay of the IJS type, the question arises as to which characteristic to select and what closing angle to set. It is suggested that the second question be answered first. When one of a number of load-carrying interconnections between two parts of a system is open there will exist between the two remote buses a phase angle difference. From a knowledge of the system, the maximum phase angle difference for which the open circuit should be reclosed can be obtained. The closing angle of the IJS should be set for this angle.

Once the closing angle is established, the next step is to settle on the maximum slip between the two parts of the system for which closing would not be objectionable, (recalling, from the previous sections, that while the IJS is basically a synchronism check relay, it can operate on an out-of-synchronism condition if the slip is slow enough). Now, from the curves of Figs. 9 and 10, using the selected closing angle and slip, determine the time dial setting for both characteristics that will do the job. In some cases both characteristics will be suitable, in others only one. When both are suitable, select either one.

It should be noted that the selection of a maximum slip must be a compromise between security and speed. That is, if the scheme is limited to very slow slips, it will be less likely to permit closing on out-of-synchronism, but it will be quite slow to operate. With closing permitted on higher slips, the scheme will be faster, but it will be more likely to permit closing on out-of-synchronism conditions. The user must make this choice.

OPERATING PRINCIPLES OF GXS12A RELAYS

The GXS12A relay is a high-speed synchronism check relay with a lockout feature. This relay is comprised of three units: A time delay (T) induction disk unit similar to that in the IJS relay, an instantaneous (I) induction cup voltage unit, and a dc-operated auxiliary lockout unit (X).

The general torque equation for the induction disk unit is the same as that for the IJS relay, as expressed by Equation (3) which is repeated below.

$$T = K_{op} (V_i + V_r)^2 - K_r (V_i - V_r)^2 \quad \text{Equation (3)}$$

The only difference is in the values of the design constants K_{op} and K_r. In the GXS relay these constants are such that the closing angle of the disk unit is approximately 85 degrees. See Fig. A on Fig. 16. The only other difference, not apparent from the equation, is the strength of the drag magnet. In the case of the disk unit of the GXS, the drag magnet is weak so that the unit operates quite a bit faster than the IJS.

The instantaneous cup unit, like the disk unit, is connected to receive both the running (bus) and incoming (line) voltages. This unit develops electrical torque (T_e) as given by the following equation:

$$T_e = K V_i V_r \sin \phi \qquad \text{Equation (4)}$$

where:

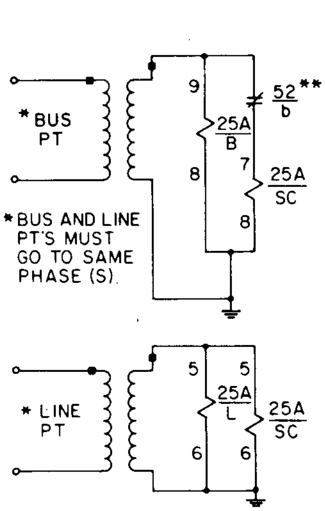
K is a design constant
V_i is magnitude of incoming voltage
V_r is magnitude of running voltage
ϕ is angle by which V_r leads V_i

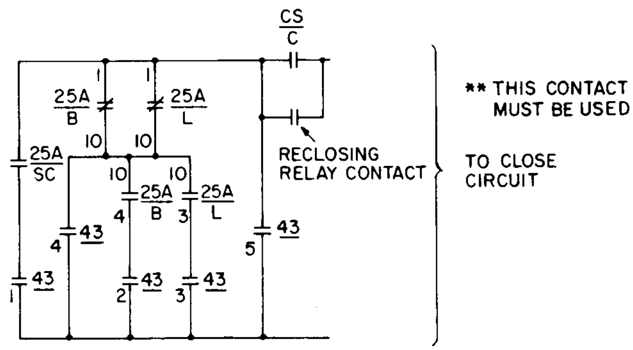
Thus, for a condition where V_r leads V_i by say 30 degrees, the electrical torque developed is

$$T_e = 0.5 K V_i V_r$$

If, on the other hand, V_i were leading V_r by the same 30 degrees, the magnitude of the electrical torque would be the same as before, but it would be negative because ϕ is now -30 degrees.

$$T_e = -0.5 K V_i V_r$$





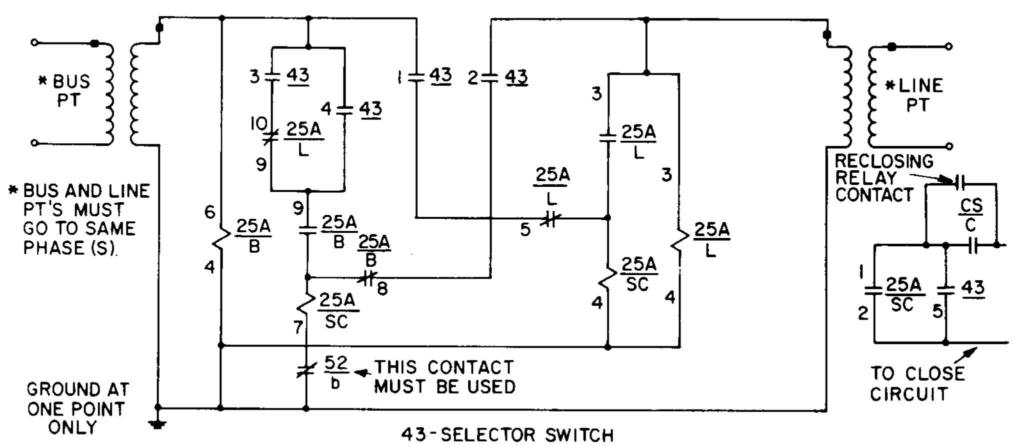
LEGEND
25A - IJS52D RELAY
B - BUS VOLTAGE UNIT
L - LINE VOLTAGE UNIT
SC - SYNCHRONISM CHECK UNIT
43 - SELECTOR SWITCH
CS - CONTROL SWITCH

43-SELECTOR SWITCH

	OFF	SYNC CHECK	DEAD LINE OR DEAD BUS	DEAD LINE AND LIVE BUS	DEAD BUS AND LIVE LINE	DEAD LINE AND LIVE BUS OR DEAD BUS AND LIVE LINE
1		X	X	X	X	X
2				X		X
3					X	X
4			X			
5	X					

NOTE: THIS SHOWS A TYPICAL ARRANGEMENT. A SIMPLER SELECTOR SWITCH WOULD BE USED IF ALL ALTERNATIVES ARE NOT REQUIRED. SYNCHRONISM CHECK IS ALWAYS IN SERVICE EXCEPT IN THE OFF POSITION.

Fig. 12. Automatic synchronism check with IJS52D. (KW-121867)



LEGEND
25A - IJS52E RELAY
B - BUS VOLTAGE UNIT
L - LINE VOLTAGE UNIT
SC - SYNCHRONISM CHECK UNIT
43 - SELECTOR SWITCH
CS - CONTROL SWITCH

43-SELECTOR SWITCH

	OFF	SYNC CHECK	DEAD BUS AND LIVE LINE	DEAD LINE AND LIVE BUS	DEAD BUS AND LIVE LINE OR DEAD LINE AND LIVE BUS
1				X	X
2			X		X
3			X	X	X
4		X			
5	X				

NOTE - THIS SHOWS A TYPICAL ARRANGEMENT. A SIMPLER SELECTOR SWITCH WOULD BE EMPLOYED IF ALL ALTERNATIVES ARE NOT REQUIRED. WITH THE ARRANGEMENT SHOWN, SYNCHRONISM CHECK IS IN SERVICE ONLY WHEN THE SELECTOR SWITCH IS IN THAT POSITION. IF SYNCHRONISM CHECK IS DESIRED AT ALL TIMES, CONTACT 4 MUST BE ONE THAT IS CLOSED IN ALL POSITIONS EXCEPT OFF.

Fig. 13. Automatic synchronism check with IJS52E. (KW-121267)

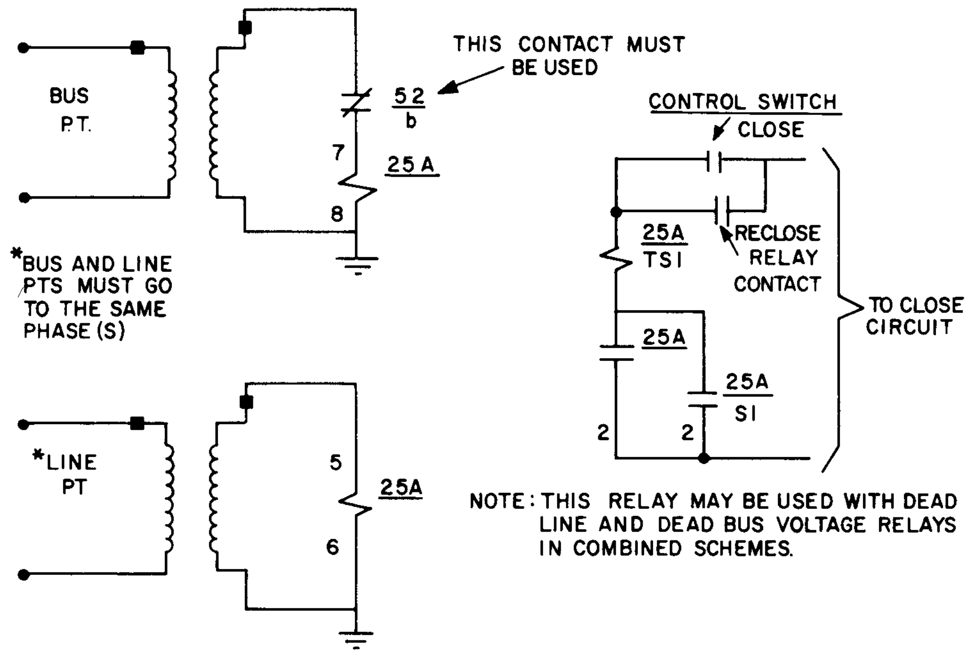


Fig. 14. Automatic synchronism check with IJS51A. (KW-121967)

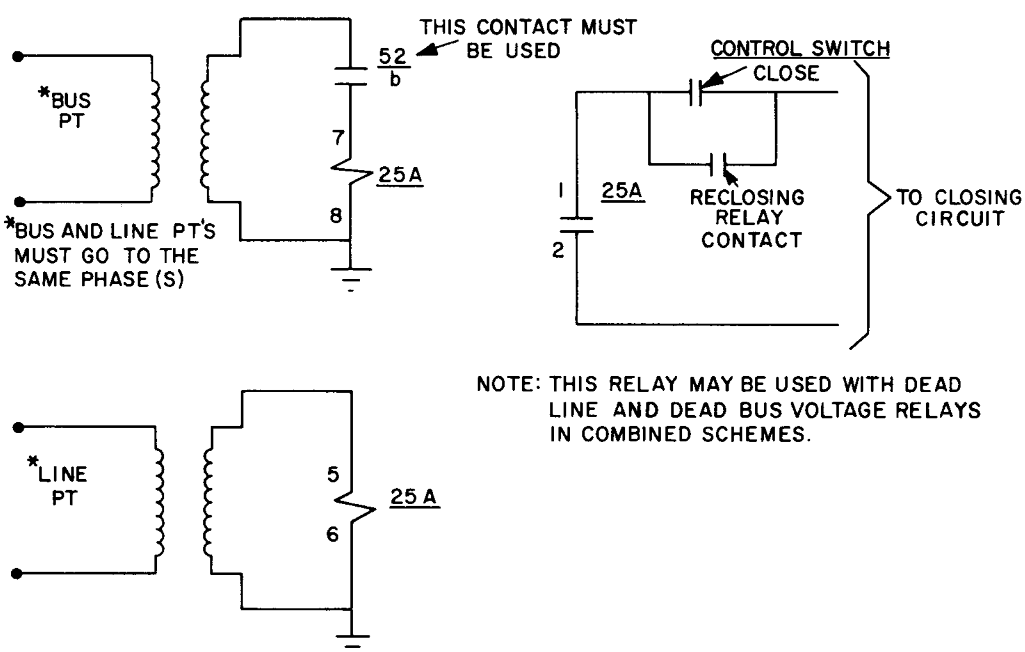


Fig. 15. Automatic synchronism check with IJS52A. (KW-122067)

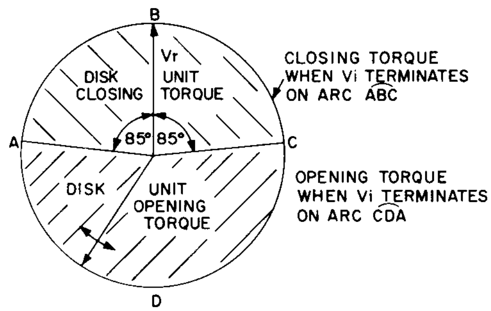


FIGURE A

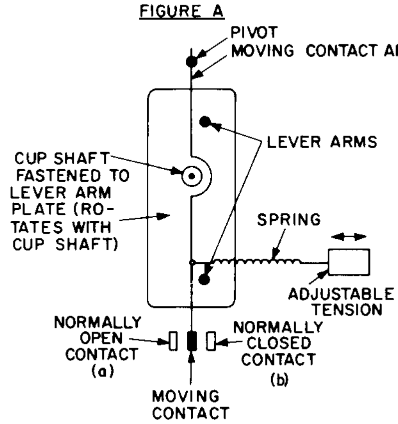


FIGURE B

Fig. 16. Time delay disk unit. (KW-020868)

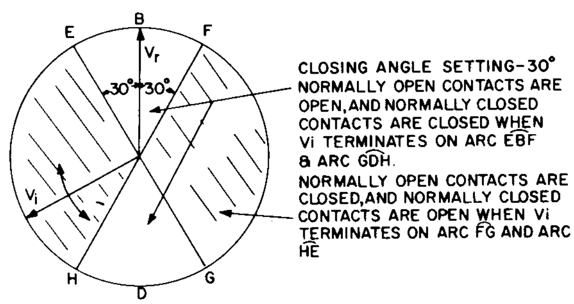


FIGURE A
INSTANTANEOUS CUP UNIT

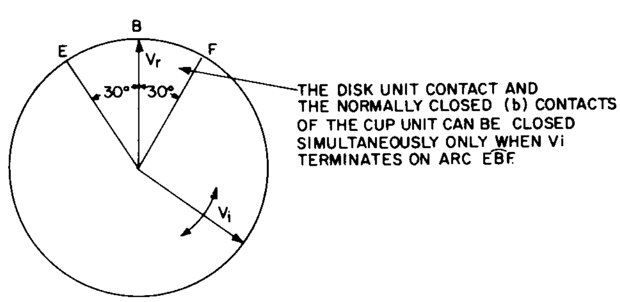


FIGURE B
CUP UNIT PLUS DISK UNIT

Fig. 17. Instantaneous cup unit. (KW-020968)

With positive (T_e) torque the cup tends to rotate in one direction, while with negative (T_e) torque the cup tends to rotate in the opposite direction. Thus, the magnitude of the torque developed at rated voltage will be proportional to the sine of the angular separation of the two voltages, but the direction of the torque will depend on which voltage is leading.

Because it is necessary for the cup unit to operate regardless of which voltage is leading or lagging as long as the angle is within the set limits, the contact assembly is arranged as shown in Fig. B of Fig. 16. As will be noted, the cup shaft is fastened to the lever arm plate so that they rotate together.

The lever arms are both fastened to the lever arm plate and move with it so that, regardless of the direction in which the cup rotates, either one or the other lever arm applies torque to the moving contact arm in the direction to close the normally open (a) contact. The spacing of these lever arms relative to the contact arm pivot and the cup shaft is such that for a given magnitude of torque on the cup, equal torque is transmitted to the moving contact arm regardless of the direction of rotation.

A spring with adjustable tension is provided against which the electrical torque on the cup must operate to open the normally closed (b) contact and close the normally open (a) contact. Thus, the balance point (or operating point) of the cup unit occurs when the electrical torque (T_e) on the cup is equal to the mechanical torque of the spring (K_s). Rewriting equation (4), the cup unit operates when

$$K_s = K\, V_i\, V_r \operatorname{Sin} \phi \qquad \text{Equation (5)}$$

It is obvious from this equation that at rated voltage the angle (ϕ) between V_i and V_r for which the cup unit operates will be directly related to the spring setting. Thus, the desired operating angle of this unit is set by the spring tension.

Consider, for example, that K_s is set for a 30-degree operating angle. This means that the normally closed contact (b) will be closed and the normally open contact (a) will be open whenever V_i is within plus or minus 30 degrees of V_r. It also means that the same will be true whenever V_i leads or lags V_r by any angle between 150 and 210 degrees. This is illustrated in Fig. A of Fig. 17 and it comes about because

$$\operatorname{Sin} \phi = \operatorname{Sin} (180° - \phi)$$

Figure B of Fig. 17 is a composite of Fig. A (Figs. 16 and 17). It indicates that the normally open contact of the disk unit and the normally closed contact of the cup unit are concurrently closed only in the range where V_i leads or lags V_r by 30 degrees, or whatever is the setting of the cup unit in the available range of 10 to 45 degrees. In this sense, the disk unit acts as a "directional" unit to block closing in the area of arc GDH of Fig. A on Fig. 17.

At this point it should be explained that the GXS relay gives permission to close when the phase angle between the two applied voltages is within the setting of the cup unit. For this condition, the disk unit is picked up and its contacts are closed, but the cup unit is in its reset position where its normally closed contact is in series with the disk unit contact in the closing circuit to permit closing of the breaker.

It should be recognized from Equation 5 that the calibration of the instantaneous cup unit is dependent on the applied voltages. For example, if the spring (K_s) is set with rated voltages applied so that the unit resets at 30 degrees, and then one of the applied voltages drops by 10 percent, the sine of the reset angle must increase by 10 percent. Thus, the reset angle ϕ will increase to 33.4 degrees. In other

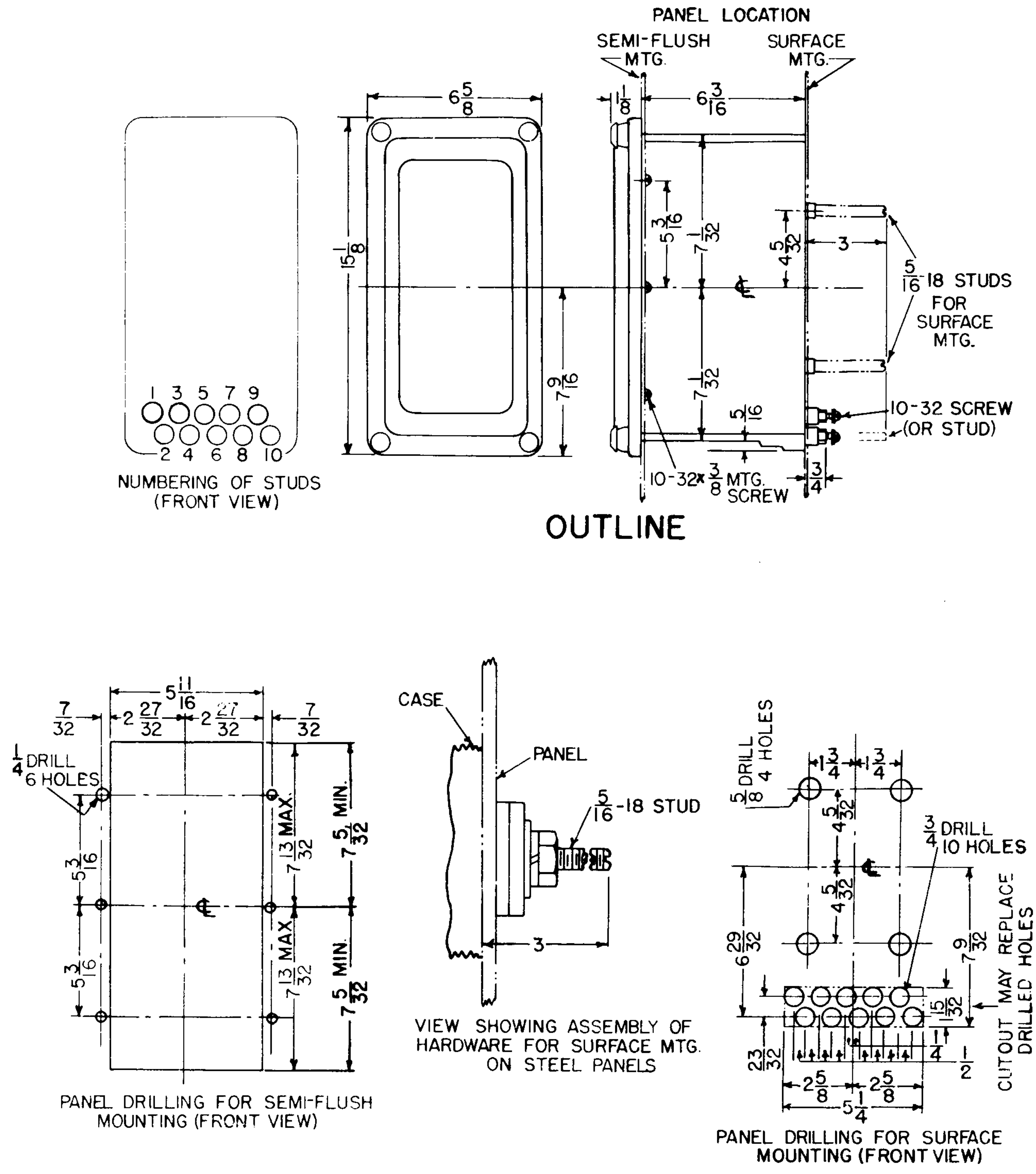


Fig. 18. Outline and panel drilling for drawout relays, size M1. (K-6209273)

words, the angle at which the relay will permit closing will increase as the applied voltage decreases and vice versa.

The effects of voltage variations on the disk unit are slight. The reason for this may be noted from Equation (3). Since the balance point (T = 0) of this unit is about 85 degrees, K_r is only slightly greater than K_{op}. (Note that for a balance point of 90 degrees, K_{op} must equal K_r since the vector difference between two voltages at that angle is equal to the vector sum). Under such conditions, moderate variations in the magnitude of one or both voltages will have only little effect on the operating angle of this unit.

As noted earlier, the GXS12A relay also includes a dc-operated auxiliary unit. This has a time delay pick-up of about six cycles, and it is incorporated in the relay to provide a lockout feature as will be discussed subsequently.

OPERATING CHARACTERISTICS OF GXS12A RELAYS

The GXS12A relay is built in a size M2 case and its outline is indicated on Fig. 18.

It will be noted from the internal connections of Fig. 19 that both the instantaneous and the time delay units have two sets of potential circuits. The external connections of Fig. 20 indicate that one set of potential coils is supplied from bus or running potential, while the second set receives line or incoming voltage. The contact arrangement in the relay is such that in order to permit closing of the breaker, the cup unit normally closed $25/I_b$ contact, the normally open 25/T contact, and the normally closed 25/X contact must all be closed simultaneously.

The $25/I_b$ contact will close immediately whenever the angle between the two applied voltages is within the setting. Thus, the over- all operating time will depend only on the time delay disk unit setting. The 25/T contact will close only if the two voltages are within about 85 degrees of one another and if they stay within that angular separation for long enough. The length of time required will depend on the time dial setting and the angle between the two applied voltages. The curves of Fig. 21 give this time as a function of time dial setting and fixed phase angle difference between the two applied voltages. The 25/X normally closed contact will be closed if lock-out has not been set up. Lock-out is set up any time that the breaker is open with both line and bus side potentials present, and the angle between the two is greater than the cup unit setting so that $25/I_a$ closes. This picks up the auxiliary 25/X which seals itself in to lock out the scheme. Thus, if the angle between the two voltages ever exceeds the closing angle setting while the breaker is open, lock-out will take place.

As in the case of the IJS relay, the disk unit can close its contacts (25/T) even during out-of-synchronism if the slip is slow enough. However, in this case, closing will be set up only if the voltages are applied at an instant when they are within the closing angle setting of the cup unit, and the slip is zero or slow enough for the disk unit to close its contacts before the angle slips beyond the cup unit setting. This is so because once the angle exceeds the cup unit setting, lock-out takes place.

The maximum slip for which the relay will permit closing may be approximated from the curves of Fig. 21 by taking the following steps:

1. For the time dial setting employed on the disk unit, read the operating time of the disk unit from the curve of phase angle difference that is the same as the closing angle setting of the cup unit.

2. Repeat (1) above for the zero phase angle curve.

3. Calculate the average time from the results of (1) and (2) above.

4. Divide twice the closing angle setting of the cup unit by 360 times the time calculated in (3) above. The result is the maximum slip cycles per second for which the relay could permit closing.

As an example, assume a No. 10 time dial setting on the disk unit and a plus or minus 30-degree closing angle setting of the cup unit. From the curves of Fig. 21, the average time is

$$\frac{1.64 + 1.4}{2} = 1.52 \text{ seconds}$$

The maximum slip for which the relay might permit closing is

$$\frac{2 \times 30}{360 \times 1.52} = 0.11 \text{ slip cycles/second}$$

It should be recognized that smaller time dial settings, and/or bigger closing angle settings will permit the possibility of closing at higher slips.

Another important characteristic to consider is the curves of Fig. 22. These curves indicate the variation in the calibration of the cup unit with applied voltages. They indicate that the magnitude of the applied voltages have a significant effect on the actual closing angle, and that the higher the closing angle setting, the greater is this effect.

APPLICATION OF GXS12A RELAYS

The GXS12A is a high-speed synchronism check relay that finds application wherever a high-speed synchronism check plus a lock-out function is required. It is extremely well suited for application in conjunction with high-speed automatic reclosing on transmission lines.

It is important to recognize that the GXS will not operate to permit reclosing unless both the line and the bus are energized. Thus, the first end of the line must be closed either without any supervision or by some combination of bus and line voltage indicating relays. As soon as the first end is closed and the line is hot, the GXS will start to perform. The external diagram illustrates a scheme that employs the GXS (device 25) plus bus and line voltage relays (27B and 27L). A selector switch (43) is indicated to select any one of a number of possible modes of operation. However, such a switch is not necessary unless the complete flexibility is desired.

Some transmission lines are equipped with shunt reactors and/or transformers at their terminals. In such cases, when the associated breakers are opened, the line continues to oscillate for some time and a voltage is maintained on this “de-energized” circuit. This voltage is normally at some frequency other than 60 Hz and can appear to the GXS relay as an out-of-step condition. This will cause the GXS to lock-out as soon as the line is de-energized. In some cases, where the natural frequency of the “dead” line is significantly different from 60 Hz, a high-speed frequency relay connected to the line side potential may be employed to block lock-out of the GXS except when the line frequency is at or near 60 Hz.

Another consideration is the performance of dead-line relays (27L) under these circumstances. The oscillating voltage on the “dead” line can keep the dead-line relays from operating and so delay closing of the first end of the line for some seconds. This may mitigate some of the advantage of the high-speed

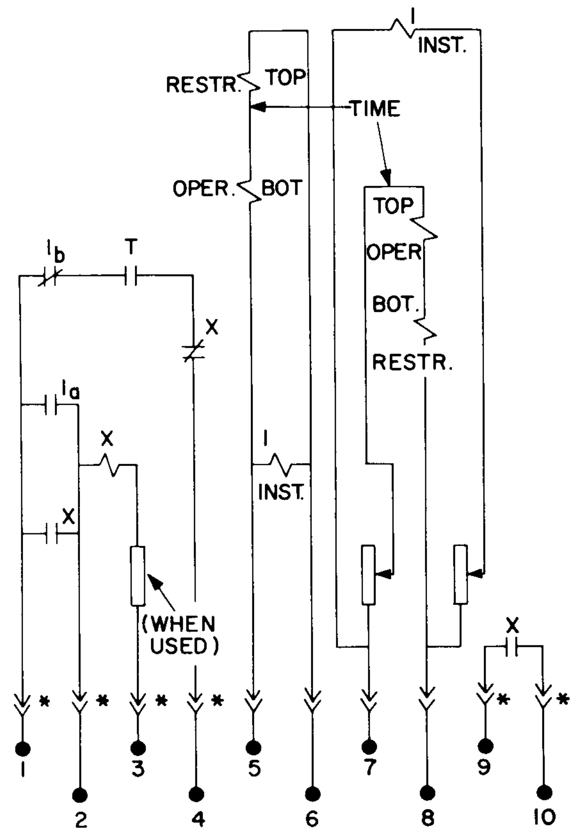
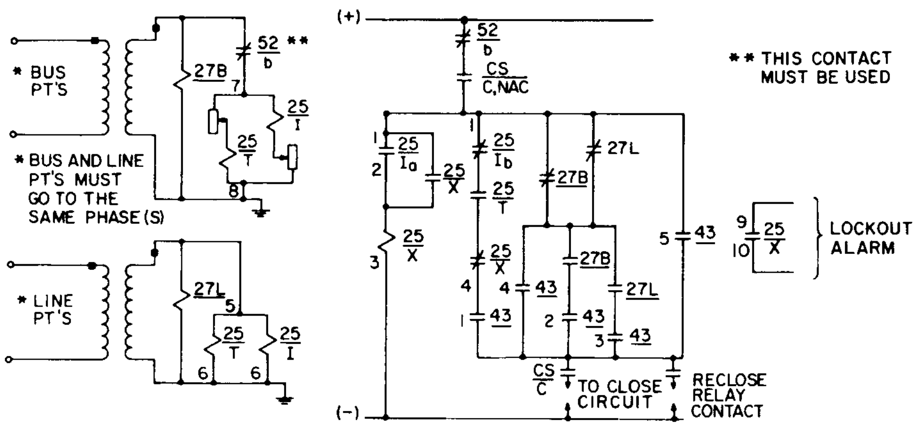


Fig. 19. Internal connections for GSX12A. (0178A7170)



LEGEND
25- GXSI2A RELAY
T- TIME DELAY UNIT
I- INSTANTANEOUS UNIT
X- AUXILIARY UNIT
27L- LINE UNDERVOLTAGE RELAY
27B- BUS UNDERVOLTAGE RELAY
43- SELECTOR SWITCH
CS- CONTROL SWITCH

43-SELECTOR SWITCH

	OFF	SYNC CHECK	DEAD LINE OR DEAD BUS	DEAD LINE AND LIVE BUS	DEAD BUS AND LIVE LINE	DEAD LINE AND LIVE BUS OR DEAD BUS AND LIVE LINE
1		X	X	X	X	X
2				X		X
3					X	X
4			X			
5	X					

NOTE: THIS SHOWS A TYPICAL ARRANGEMENT. A SIMPLER SELECTOR SWITCH WOULD BE USED IF ALL ALTERNATIVES ARE NOT REQUIRED. SYNCHRONISM CHECK IS ALWAYS IN SERVICE EXCEPT IN THE OFF POSITION.

Fig. 20. High-speed synchronism check with GXS12A. (KW-021268)

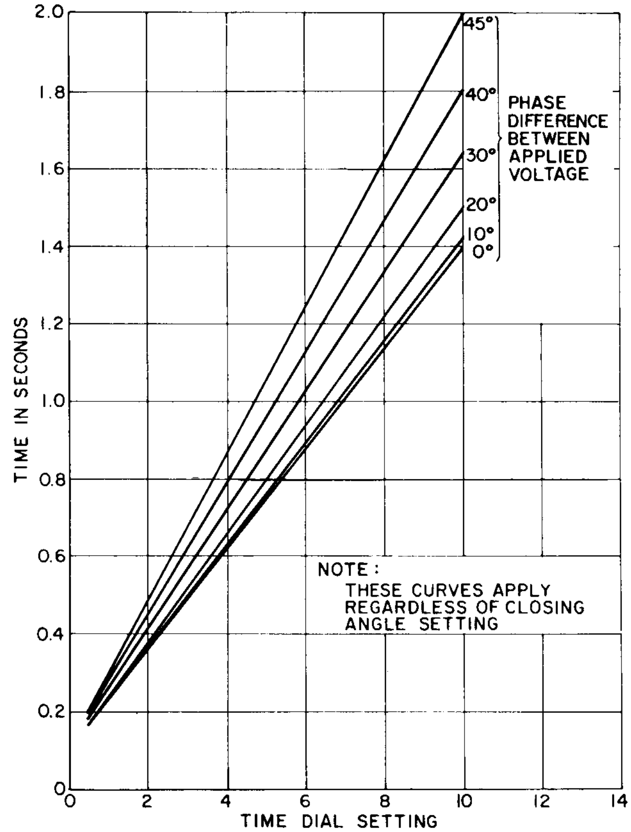


Fig. 21. Operating time of GXS12A relay as a function of time dial setting and the angle between the two applied rated voltages. (0178A8169)

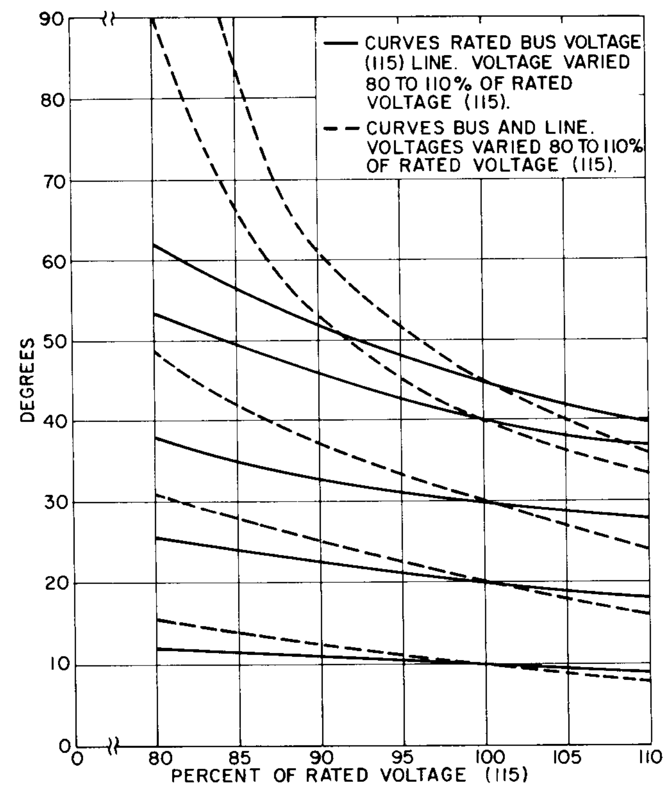


Fig. 22. Closing angle as a function of applied voltage for GXS12A. (K-6400394)

synchronism check scheme and can be avoided by permitting the first end of the line to reclose unsupervised.

There are only two settings that can be made on the GXS12A relay, and these are:

1. Closing Angle setting on the cup unit by means of the control spring

2. Time Dial setting on the disk unit.

The closing angle setting should be large enough to ensure that the GXS does not lock-out for any condition of load transfer and system swing after a trip out. As noted in the previous section under "OPERATING CHARACTERISTICS OF GXS12A", the closing angle is voltage sensitive and the curves of Fig. 22 should be consulted before settling on a setting for the closing angle.

The time dial setting on the disk unit will affect the operating time of the scheme. Lower time dial settings will permit faster reclosing. However, lower settings will permit reclosing on faster slips. This should be evaluated as outlined in the previous section on "OPERATING CHARACTERISTICS OF GXS12A" before a time dial setting is selected.

The 52/b contact shown in the potential circuit on Fig. 20 is required to prevent wear on the disk unit over long periods of time as a result of vibration when the breaker is closed and the running and incoming voltages are in phase. When desirable, this contact may be replaced by a contact on the closing device so that the GXS will not operate until "requested" to do so.

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