RESISTANCE WELDING DATA BOOK

Theory and Practice

Fourth Edition

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illustrates an exaggerated condition. In spot welding thick sheets, the welding current spreads over a large area because the thicker the two sheets, the more the total pressure will distribute itself over the surface of contact of the two sheets without being concentrated in a definite spot.

Figure 28 shows the effect of pressure and current distribution on thin and thick sheets. The slight deformation in the thin sheet tends to concentrate the welding current in the area to be welded.

Pressures for Spot Welding Low Carbon Steel—In many cases it will be found that the most suitable pressure for welding cold rolled steel will be dictated by the geometry of the parts to be joined and the nature of the specific application.

These pressures are based on a unit pressure of 14,000 psi. on the electrode face. For cold rolled steel stock, up to 3/16 inch thick, unit pressures of from 12,000 to 18,000 psi. have been found satisfactory in spot welding.

In welding scaly steel the pressure should be 18,000 to 30,000 psi. It may be stated generally that the pressure should be increased with shorter weld time because short current timing necessitates a higher current density.

Power Supply for Resistance-Welding Machines

An adequate power supply is one of the requisites of present-day, high-production resistance welding. A major part of the power supply system of any industrial plant lies within the plant itself and consists of the plant wiring and transformer substations. It is purposed to show how to properly lay out such a plant distribution system for serving welders. Much of the fundamental data included in the tables and charts is included in order that the layout engineer will have complete information available.

General Considerations—A resistance welding transformer should be designed to keep the kilovolt-ampere input as low as possible for a given welding current output and in the installation of the welding machine adequate power facilities must be provided to handle the required inputs.

The American Institute of Electrical Engineers, Committee on Electric Welding, Subcommittee on power supply for welding operations, have compiled data indicating a recommended approach to provide adequate power supply for resistance welding installations and prescribed methods of calculating load characteristics.

The information in this section has been derived liberally from the AIEE transactions. Because of the high currents involved, transformers should be located as close to the welders as possible, keeping the secondary bus and feeder runs short. In many cases it will be found advantageous to use transformers containing a liquid that will not burn rather than oil in order that they can be located adjacent to the welding machines rather than at some relatively remote outdoor or vault location. With the load power factor generally falling between 20 and 40 per cent, it is essential that the reactance of the power supply system be kept at a minimum. Generous copper cross section in welding feeders is usually less important than proper spacing and arrangement of the conductors for minimum reactance.

The first question to be answered is: "For what voltage drop shall the supply system be designed?" No specific answer can be given which will apply to all cases and satisfactory results may be obtained with 15 per cent regulation in one case and 5 per cent may be too much in another. However, in general with the usual class of production resistance welding involving low and medium carbon steels, satisfactory welding will result if the voltage drop to a point on the supply system common to two or more machines does not exceed ten per cent for the largest machine of the group. This statement is based on the assumption that there are relatively few large machines in the group being served (say, not over five or ten machines) and that, while two of them may occasionally operate at the same time, the chances of three or more operating together is extremely remote. Thus, if the machines are adjusted for perfect welding with a ten per cent voltage drop in their supply circuit, the welds will still be good when two machines operate together causing nearly 20 per cent drop. If three or more happen to hit together, poor welds or rejects may result. Care should be exercised in adjusting machines, with the setting made under highest voltage and maximum current conditions, just short of burning the weld so that under minimum voltage conditions a good weld will still result.

Experience indicates that this general rule of ten per cent drop for the largest machine will result in a good workable installation in most cases although it should be realized there will be exceptions. The procedure outlined in the following sections will follow the ten-per-cent rule with some indication as to how to determine those installations which will require special consideration as exceptions to the general rule.

Where even less than ten per cent regulation can be provided at about equal cost, such as obtained by close spacing of feeders, this obviously should be done. The ten-per-cent figure is set only as an approximate allowable upper limit and any improvement below this value is all to the good and makes for that much better welding conditions.

Interlocking can be resorted to under some conditions to insure not more than one or two machines operating at the same time. This is an inexpensive practice where only a few large machines are involved and in most cases production speed is not materially reduced.

While the current-carrying capacity of the supply feeders and transformers must receive consideration, if provision is made to keep the voltage drop within the necessary limits, there usually will be sufficient attendant thermal or carrying capacity.

Voltage Drop

For convenience, the supply system can be broken up into three parts:

1. High-voltage power supply system (2,400 volts or higher)
2. Step-down transformer bank
3. Low-voltage bus or feeder (240 or 480 volts)

High-Voltage Power Supply System

The high-voltage power supply system in most cases is the power company's service to the plant. Where the plant generates its own power, it is typified by the generator bus system. In most cases very little can be done toward reducing the voltage drop in the high-voltage power supply system at a cost commensurate with the expenditure needed for the same percentage reduction in the low-voltage system.

In the case of service from a power company, the amount of voltage drop for a given welding load is dependent upon the relative location of the industrial plant with respect to the power company's large distribution substations as well as generating stations. If the plant is in an established industrial area served by large substations and not too far from large generating stations, the voltage drop in the high-voltage system will be a negligible factor. However, if the plant has been located in a rural or small-town area far removed from the power company's main generating stations, as is becoming more common under the present-day trend toward decentralization of industry in the search for low manufacturing costs and reduced taxes, the high-voltage system regulation may loom up as a very troublesome factor. Any plant in which resistance welding is extensively used should carefully investigate this matter of high-voltage system regulation when contemplating moving the plant to any other location with less adequate power facilities for welding.

In the case of private power generation, the voltage drop at the generator bus will be inversely proportional to the total rating of generators feeding the bus. The small and moderately sized plant will experience considerable difficulty in handling any but the smaller-sized welding machines without encountering lamp flicker problems in their plant and office lighting.

The first step in designing the plant wiring and bus layout for welding is to determine the high-voltage system regulation. This can be obtained from the local power company by giving them the maximum kilovolt-amperes and power factor that the largest machine will draw from the power system. Subtract the figure obtained from the total allowable ten per cent and the remainder is that which can be allowed in the step-down bank and secondary or low-voltage bus system. For instance, assume the largest welder is rated 300 kva and will deliver a maximum welding current of 100,000 amperes with a high secondary open circuit voltage of 8 volts. The approximate maximum kilovolt-ampere input (neglecting exciting current) is $(100{,}000 \times 8)/1{,}000 = 800$ kva. From the power company representative it is learned that 800 kva at an estimated 30 per cent power factor will cause four per cent drop in the power company service to the transformer bank at the customer. This subtracted from ten per cent leaves six per cent which can be used up in the step-down transformers and low voltage bus system.

Step-Down Transformer Bank

On the assumption that the remaining allowable six per cent drop can be divided about equally between the step-down transformer bank and low-voltage bus system, it is necessary to select the proper size transformer which will limit the drop to about three per cent.

Welders can either be served from a single-phase transformer bank or a three-phase bank, and where the welding load is large enough to justify a separate transformer bank for welding load only, it will be found advantageous and more economical of capacity to use a single phase system. The load is single phase and it will remain single phase no matter how the transformers ahead of it are connected. Sometimes it is desirable to spread the individual single-phase loads over the three-phase wires for more economical utilization of the supply lines, but unless there are large numbers of machines connected, the necessity for balancing the load is not important. When there are many machines, they are usually scattered around in different parts of the plant so that several step-down banks become necessary at different locations. In this case individual single-phase banks can be connected to separate phases and thus bring about some semblance of balance on the supply wires.

A given kva of single-phase load fed from a three-phase transformer bank will cause just twice as much transformer voltage drop as the same kva load fed from the same capacity in transformers connected as a single-phase bank. It is thus obvious that, where the transformer voltage drop must be kept at a minimum, it is highly desirable and more economical to use single-phase, step-down banks of transformers.

In case the welding load is relatively small in comparison with the motor and other power load of the plant, it can readily be served from the same three-phase bank serving the power load. Individual plant and service conditions thus dictate whether single-phase or three-phase banks are the logical selection. Irrespective of whether the welding load is served from single-phase transformers or from three-phase transformers in combination with the motor and power load, the lighting load should usually be handled separately in order to prevent flicker difficulties.

Figure 29 shows per cent voltage drop per 1,000 amperes of 30 per cent power factor welding current through transformer banks of different sizes and impedance. Plant practice may determine the size and impedance of individual transformers and the number of units to connect in parallel can be determined from the chart. For instance, assume that 300-kva, 3½ per cent impedance transformers are used by this particular plant in its step-down banks. A load of 800 kva represents 1,670 amperes at 489 volts. From figure 29: 1,670 amperes through a 300 kva, 3½ per cent impedance transformer causes 1.67 times 5.6 per cent = 9.4 per cent = voltage drop. Therefore, three transformers in parallel would have to be used to stay within the predetermined limit of three per cent drop. In some cases a special low-impedance transformer may be economically justified. For example, if a two-per cent impedance transformer is purchased, the nearest

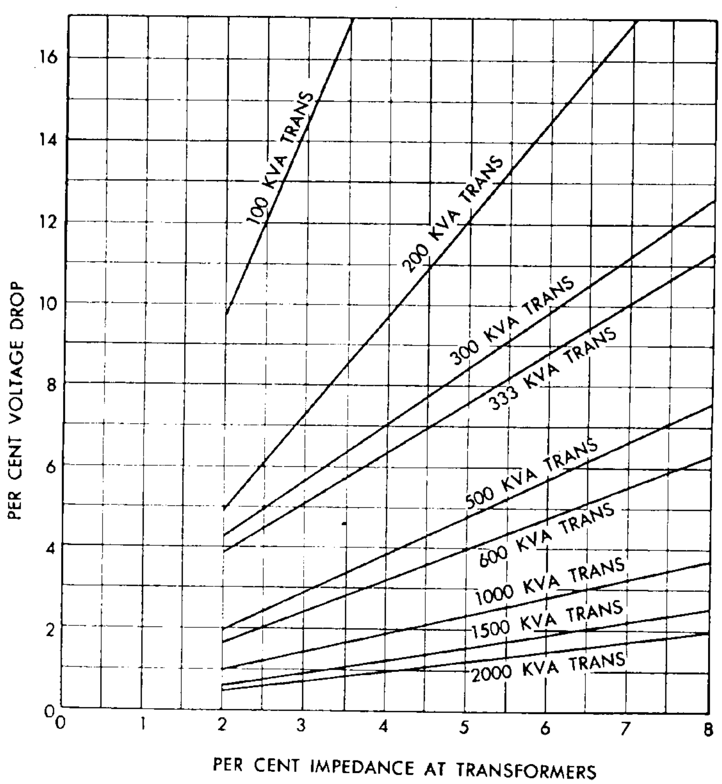

FIG. 29

Per cent voltage drop per 1,000 amperes of 30 per cent power factor single-phase welding current.

1. For 480-volt, single-phase transformer bank, use chart values of per cent voltage drop.
2. For 480-volt, three-phase transformer bank, multiply per cent voltage drop by 2.
3. For 240-volt, single-phase transformer bank, multiply per cent voltage drop by ½.
4. For 240-volt, three-phase transformer bank, use chart values of per cent voltage drop.

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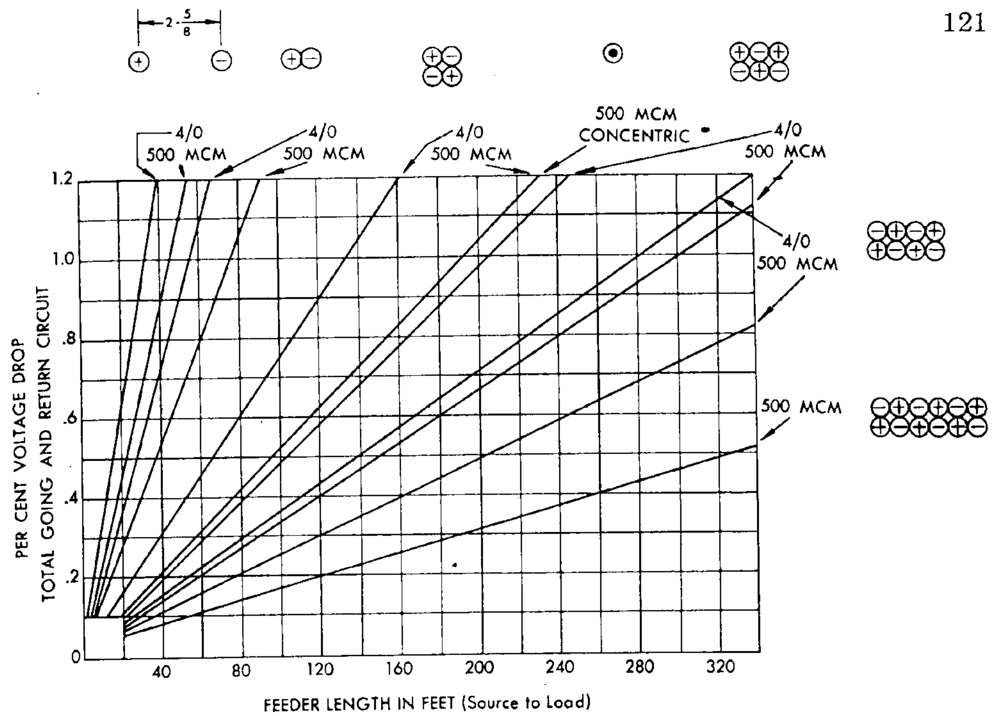
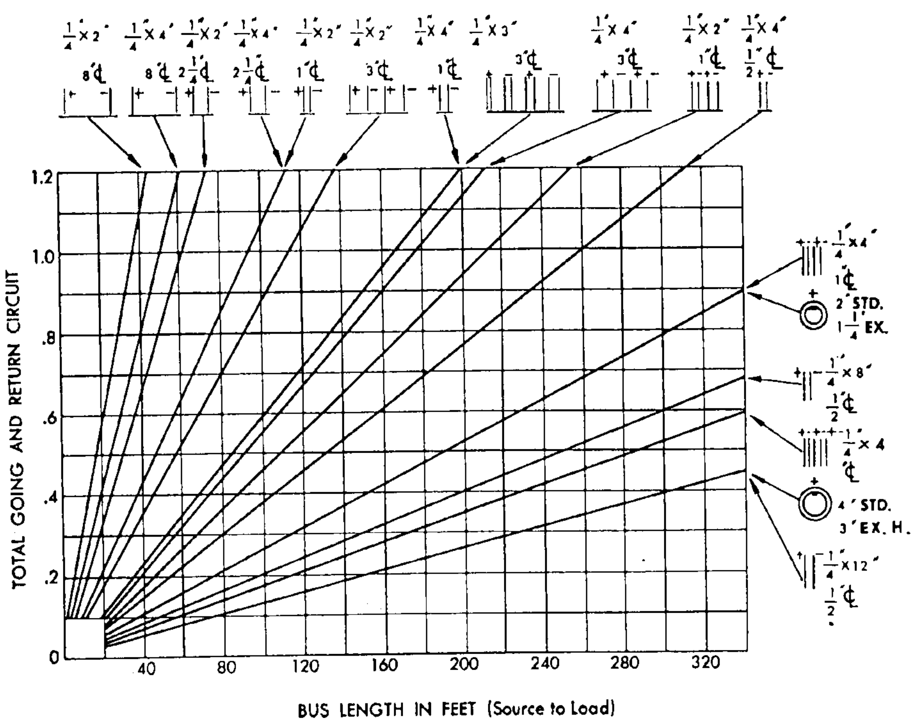


Per cent voltage drop per 1,000 amperes of 30 per cent power factor, single-phase welding current.
1. For 480-volt feeder, use chart values of per cent voltage drop.
2. For 240-volt feeder, multiply per cent voltage drop by 2.

FIG. 30—*Welding supply—wire feeder regulation.*



Per cent voltage drop per 1,000 amperes of 30 per cent power factor, single-phase welding current.
1. For 480-volt bus, use chart values of per cent voltage drop.
2. For 240-volt bus, multiply per cent voltage drop by 2.

FIG. 31—*Welding supply—bus regulation.*

size transformer would be 500 kva which would allow 3.2 per cent drop. This might be cheaper than the three 300 kva transformers but would have the definite disadvantage of not being usable interchangeably at other plant locations. If a plant has sufficient welding load, it sometimes pays to standardize on special low-impedance transformers for welding only and not attempt to make them interchangeable with transformers used in power and lighting banks.

Low-Voltage Bus or Feeder

There is now only three per cent remaining out of the original allotted ten per cent drop. It is found that the bus or feeder must be 300 feet in length to reach the two machines located farthest from the transformer bank.

Figures 30 and 31 show the per cent voltage drop per 1,000 amperes of 30 per cent power factor welding current for different types and sizes of bus and wire construction. Figure 30 is for various wire arrangements and Figure 31 for different bus arrangements. Some plant engineers prefer one class of construction and some the other. The bus can be made up on the job or it can be purchased, prefabricated in unit lengths either with or without enclosures.

Usually if the welders are in a fairly compact group but at some appreciable distance from the transformer bank, some arrangement of wire feeder works out to advantage. However, where the machines are scattered and frequent taps must be made to the supply wires or bus, a bus system is perhaps more advantageous in that frequent connections to it are readily made.

From the charts it is found that two 500,000 circ-mil wires per leg in conduit would handle 800 kva with 2.6 per cent drop at the 300-foot distance. (800 kva = 1,670 amperes. From the chart the drop for 150 feet = 0.78 per cent; for 300 feet and 1,670 amperes the voltage drop equals 0.78 per cent times 2 times 1.67 = 2.6 per cent.) For the bus construction a bus consisting of two ¼ inch by 4 inch copper bars on one-inch centers would be suitable from a voltage-drop standpoint.

It is possible that either of these selections may have sufficient current-carrying capacity for handling the equivalent steady or thermal load of the group of welders. However, if it is found that more carrying capacity is needed, other configurations are shown with equal or better voltage-drop characteristics.

Equivalent Continuous Thermal Loading

There are several ways in which the equivalent continuous thermal loading of a group of welders can be determined. It might be reasoned that the quickest and simplest method would be to add the name-plate kilovolt-ampere ratings of the individual welding transformers, and then apply a suitable diversity factor for group operation. The welding transformers are rated on a 50-per-cent duty-cycle basis and, consequently, if all of the machines are operated continuously right up to the thermal capacity of their transformers, the equivalent continuous thermal loading would be $\sqrt{0.50}$ or 70.7 per cent of the sum of the name plate ratings. Thus, if there were ten 300-kva welders, the supply system on this basis should have a carrying capacity of 70.7 per cent of 3,000 kva, or 2,100 kva less the diversity factor correction.

In actual practice, however, most machines, except perhaps some seam welders, operate well below their maximum thermal capacity, because the size of transformer in the machine is dictated by the required welding current output rather than by thermal considerations.

Tests of many installations show that the values given in Table 8 are more clearly representative of actual field conditions. Thus, if the machines are predominately spot, projection, or flash welders, a supply system with a rating of 15 per cent of the sum of the name-plate ratings of the machines would, in most cases, be adequate. Thus, taking the ten 300 kva welders, the supply system should be good for about 15 per cent of 3,000 kva, or 450 kva.

TABLE 8—*Equivalent Continuous Loading of Typical Welding Machine Installations.*

Types of Welding	Equivalent Continuous Load Expressed in Per cent of Sum of Name-Plate Ratings
Spot, projection, flash	5 to 10 (most installations) 10 to 20 (very few installations)
Hydromatic, butt	10 to 20
Seam	25 to 70

A second check should be made based upon the actual kilovolt-ampere loads of the welders and their operating duty cycles. Assume that each of the ten 300-kva machines was on a production schedule of 100 welds per hour with maximum loads of 800 kva for 10 cycles per weld. The corresponding duty cycle of each machine is: $(10 \times 100)/(60 \times 60 \times 60) = 0.46$ per cent. The equivalent continuous load corresponding with 800 kva at 0.46 per cent duty cycle is: $\sqrt{0.0046} \times 800$ kva $= 54$ kva. For the total of ten machines, if all were operating at peak production, the equivalent kilovolt-amperes would be $10 \times 54 = 540$ kva.

The selection of three 300-kva transformers on the basis of voltage-drop considerations is thus perfectly safe from the standpoint of current-carrying capacity. The 500-kva, 2-per-cent-impedance transformer might be just a little small from a thermal capacity standpoint for ten machines in peak production but, with the usual diversity of group operation, should be adequate.

Tables 9 and 10 show the equivalent carrying capacity in continuous amperes of the various types of bus and wire arrangements commonly used. The ampere load corresponding with an equivalent continuous thermal load of 500 kva at 480 volts is approximately 1,000 amperes. Thus, the wire construction previously selected on the basis of voltage drop is not large enough from the standpoint of current-carrying capacity. A wire grouping consisting of four 500,000-circ-mil wires per leg (item 11, Table 9) is rated about 1,000 amperes and should be adequate for the job. This wire arrangement will have only 1.2 per cent voltage drop for an 800-kva load swing, thus being well within the three per cent allowed.

It should be emphasized here that the current-carrying capacities given in Table 9 for six or more total wires in a trough or raceway enclosure are estimated values only and while considered to be reasonable approximations, they are subject to change whenever verifying test data become avail-

TABLE 9—*Welding Supply—Wire Feeder Data.*
Calculated Data per 100 Feet of Distance from Source to Load (200 Feet of Circuit).

Item	Wires Per Leg	Spacing (See Figure 2)	Size	Area Square Inches	Approximate Current-Carrying Capacity Copper 60 Deg C Ambient 30 Deg C (Amperes).	Weight (Pounds)	D-C Resistance 25 Deg C (Ohms)	Reactance (Ohms)	Voltage Drop Per 1,000 Amperes 30 Per Cent Power Factor: Volts	Voltage Drop Per 1,000 Amperes 30 Per Cent Power Factor: Per Cent at 480 Volts
1	1	2 5/8-inch centers	4/0	0.166	225[1]	131	0.01	0.012	14.3	2.98
2	1	2 5/8-inch centers	500,000 circ-mil	0.393	400[1]	308	0.0043	0.0098	10.7	2.22
3	1	Wires laced together	4/0	0.166	210[2]	131	0.01	0.0059	8.72	1.82
4	1	" " "	500,000 circ-mil	0.393	350[2]	308	0.0043	0.0056	6.63	1.38
5	2	" " "	4/0	0.332	400[2]	261	0.0051	0.0022	3.63	0.76
6	1	Concentric cable	500,000 circ-mil	0.393	300[5]	308	0.0043	0.0013	2.53	0.53
7	2	Wires laced together	500,000 circ-mil	0.786	650[2]	616	0.0022	0.002	2.54	0.53
8	3	" " "	4/0	0.498	500[3]	392	0.0034	0.0014	2.36	0.49
9	4	" " "	4/0	0.664	600[3]	522	0.0026	0.001	1.72	0.36
10	3	" " "	500,000 circ-mil	1.18	850[3]	925	0.0014	0.0013	1.63	0.34
11	4	" " "	500,000 circ-mil	1.58	1,000[3]	1,230	0.0011	0.00089	1.17	0.24
12	6	" " "	500,000 circ-mil	2.36	1,300[3]	1,850	0.00072	0.0006	0.79	0.17

NOTES: 1. Code limit.
2. In conduit, wires laced together.
3. In trough, wires laced together (estimated values—no test data known).
4. Reactance is slightly higher when wire is in magnetic trough or conduit.
5. In conduit (estimated value—no test data known).

TABLE 10—*Welding Supply—Bus-Bar and Tubing Data.*
Calculated Data per 100 Feet of Distance from Source to Load (200 Feet of Circuit).

Voltage Drop Per

3. In trough, wires laced together (estimated values—no test data known).
4. Reactance is slightly higher when wire is in magnetic trough or conduit.
5. In conduit (estimated value—no test data known).

TABLE 10—*Welding Supply—Bus-Bar and Tubing Data. Calculated Data per 100 Feet of Distance from Source to Load (200 Feet of Circuit).*

Item	Bars Per Leg	Spacing (See Figure 3)	Size (Inches)	Area Square Inches	Approximate Current-Carrying Capacity 35-Deg C Rise (Amperes)		Weight (Pounds)	D-C Resistance 25 Deg C (Ohms)	Reactance (Ohms)[3]	Voltage Drop Per 1,000 Amperes 30 Per Cent Power Factor	
					Open	Housing[2]				Volts	Per Cent at 480 Volts
1	1	8″ centers	1/4x2	0.5	750	490	386	0.0033	0.0126	13.0	2.71
2	1	8″ "	1/4x4	1.0	1,400	950	772	0.0017	0.0098	9.84	2.05
3	1	2 1/4″ centers	1/4x2	0.5	750	490	386	0.0033	0.0072	7.86	1.64
4	1	2 1/4″ centers	1/4x4	1.0	1,400	950	772	0.0017	0.0048	5.07	1.06
5	1	1″ centers	1/4x2	0.5	720	450	386	0.0033	0.0041	4.91	1.02
6	2	3″ centers interlaced	1/4x2	1.0	1,400	950	772	0.0017	0.0039	4.19	0.87
7	1	1″ centers	1/4x4	1.0	1,370	900	772	0.0017	0.0025	2.88	0.60
8	2x2	3″ centers interlaced	1/4x3	3.0	3,600	2,600[4]	2,315	0.00056	0.0028	2.84	0.59
9	2	3″ " "	1/4x4	2.0	2,600	1,800[4]	1,544	0.00084	0.0026	2.73	0.57
10	2	1″ " "	1/4x2	1.0	1,350	870	772	0.0017	0.0018	2.25	0.47
11	1	1/2″ centers	1/4x4	1.0	1,370	900	772	0.0017	0.0014	1.83	0.38
12	2	1″ centers interlaced	1/4x4	2.0	2,500	1,700[4]	1,544	0.00084	0.0011	1.27	0.26
13	1	2″ Standard tube around 1 1/4 extra heavy tube		1.09 / 0.89	800		765	0.0017	0.00078	1.25	0.26
14	1	1/2″ centers	1/4x8	2.0	2,600	1,800[4]	1,544	0.00084	0.00076	0.98	0.20
15	3	1″ centers interlaced	1/4x4	3.0	3,500	2,400[4]	2,315	0.00056	0.0007	0.83	0.17
16	1	4″ Standard tube around 3 extra heavy tube		3.18 / 3.05	2,000		2,410	0.00054	0.0005	0.64	0.13
17	1	1/2″ centers	1/4x12	3.0	3,600	2,500[4]	2,315	0.00056	0.0005	0.64	0.13

NOTES: 1. Extrapolated from test data.
2. Housing material, size, and color affect rating to marked degree.
3. Reactance may be as much as 5 per cent to 20 per cent higher if bus is in magnetic housing.
4. Nonmagnetic housing.

TABLE 11—*Chance of Simultaneous or Interfering Welds.*

Number of Machines	Weld Time (Cycles)	Welds Per Hour Per Machine	Total Output Per Hour	Time Interval Between Simultaneous Welds: Two Welds Together	Time Interval Between Simultaneous Welds: Three Welds Together	Number of Good Welds for Every Weld in Which Three Hit Together	Total Time Divided by Weld Time of All Welders
5	3	100	500	52 hr	12,500 hr	6,250,000	144
5	3	200	1,000	6.5 hr	777 hr	777,000	72
5	3	300	1,500	1.9 hr	154 hr	231,000	48
5	10	100	500	4.2 hr	336 hr	168,000	43
5	10	200	1,000	35 min	21 hr	21,000	22
5	10	300	1,500	10 min	4.2 hr	6,200	14
3	30	100	300	2.9 hr	207 hr	62,200	24
3	30	200	600	22 min	13 hr	7,760	12
3	30	300	900	6 min	2.6 hr	2,310	8
5	30	100	500	31 min	12.4 hr	6,220	14
5	30	200	1,000	4 min	47 min*	778	7
10	3	100	1,000	5.8 hr	518 hr	518,000	72
10	3	200	2,000	43 min	32.4 hr	65,000	36
10	3	300	3,000	13 min	6.4 hr	19,200	24
10	10	100	1,000	31 min	14 hr	14,000	22
10	10	200	2,000	4 min	52 min*	1,743	11
10	10	300	3,000	1 min	10 min*	520	7
10	30	100	1,000	3 min	28 min*	467	7
20	3	100	2,000	41 min	27 hr	54,000	36
20	3	200	4,000	5 min	1.7 hr	6,840	18
20	3	300	6,000	2 min	20 min*	2,020	12
20	10	100	2,000	4 min	44 min*	1,480	11

*NOTE: On border line of unsatisfactory operating conditions if supply system is designed for ten per cent voltage drop for operation of largest machine. For these conditions supply system should probably be designed for about five per cent voltage drop.

able. The current-carrying capacities for most of the bus arrangements in Table 10 are extrapolated from test data of similar configurations both in the open and in metal enclosures and should, consequently, be reasonably accurate although here again, actual test data would be welcomed by the industry.

Similarly, table 10 shows several types of bus construction well within the three-per-cent voltage-drop allowance which will have adequate carrying capacity. The original selection of one ¼ inch by 4 inch bar per leg on one-inch centers would be adequate if mounted in the open. However, most bus installations will require enclosures and on this basis the selection would be between the heavier current-carrying busses having drops of less than three per cent.

Chance of Simultaneous Welds

Designing for a total of ten per cent voltage drop for the operation of the largest machine produces satisfactory welding conditions only when three or more machines do not happen to operate at the same instant. Based upon the general law of averages, the expectancy of simultaneous welds can be readily calculated. For the sake of simplicity, it is assumed that even if only a single cycle of one weld overlaps another, this would constitute a simultaneous weld. Obviously, except for very short-time welds (two to three cycles) a single cycle overlap should not prove serious and this assumption thus introduces a considerable factor of safety.

T = total time per weld per machine, including "off" and loading time as well as actual weld time

t = actual weld time per machine

E = number of machines

$\frac{T}{tE} \times \frac{T}{t(E-1)}$ = interval in terms of number of welds between operations in which two machines make a weld at the same time including any slight overlapping of actual welding time

$\frac{T}{tE} \times \frac{T}{t(E-1)} \times \frac{T}{t(E-2)}$ = interval in terms of number of welds between operations in which three machines make a weld at the same time including any slight overlapping of welding time

In usual production welding if rejects due to simultaneous welds do not occur oftener than once per hour, which would be one weld out of every 5,000 or 10,000, conditions would probably be considered highly satisfactory. Table 11 shows various combinations of machines, welding time, hourly production, and corresponding interval of time between expected simultaneous welds. For instance, 20 machines with three-cycle welding can produce 200 welds per hour per machine with an expectancy of three simultaneous welds and three rejects every 1.7 hours. With the production stepped up to 300 welds per hour per machine, the resultant expected interference might be such that it would be desirable to either split the machines into two groups or design for a five per cent instead of ten per cent voltage drop in the supply system.

The last column shows total time divided by the actual weld time of all large machines on the bus. As long as this value is greater than 10 or 20, satisfactory welding conditions should generally result on a supply system

between operations in which three machines make a weld at the same time.
Three welds together every 14,000/1,000 = 14 hours
Total time divided by weld time of all welders = $(60 \times 60 \times 60)/(10 \times 10 \times 100) = 21.6$

Interlaced Bus Calculations

The reactance values of the various wire groupings and bus-bar configurations shown in Figures 30 and 31 and in Tables 9 and 10 were calculated by means of the following short-cut method, utilizing the charts of reactance for a pair of conductors (either for conductors, Figure 32, or standard strand cables, Figure 33).[1] In this way it is possible to calculate the reactance of an interlaced bus or cable system with a reasonable degree of accuracy in a few minutes, as compared with the more laborious method based upon the fundamental relations of mutual and self-inductance which at best requires several hours.

This short-cut method of calculation is incorporated as part of this report in order that quick calculations can be made for other wire or bus configurations than those shown in the tables.

The basic methods and curves used here are not new, but were published in U. S. Bureau of Standards Scientific Paper No. 281 by Francis B. Silsbee, and also in The Electric Journal of June 1919 in an article entitled "Reactance Values for Rectangular Conductors" by H. B. Dwight. However, it was felt desirable to bring together all of the necessary data for the calculation of welder bus reactance and to show by actual examples the use of these data for the calculation of interlaced conductors.

The more general types of welder busses which are commonly used are: (1) four or more stranded insulated conductors interlaced and clamped together, (2) interlaced copper bars, and (3) concentric tubes. Figures 32 and 33 show the total reactance, self minus mutual, between two conductors. The same curves can be used in the following manner when more than two conductors are involved and there is an even number of conductors. Consider an interlaced bus consisting of six conductors, three going and three returning, as shown in item 15, Table 10, arranged as follows:

$$(+1)\quad(-4)\quad(+2)\quad(-5)\quad(+3)\quad(-6)$$

Since the average drop of the going circuit equals the average drop of the return circuit, it is only necessary to find the drop in the going circuit and multiply it by two to determine the total circuit drop. If, as a first approximation, it is assumed that the current divides evenly between all of the going conductors, the reactance of any going conductor is the sum of the reactances of all the return conductors to the given going conductor minus the reactance of the remaining two going conductors to the given going conductor. Dividing the sum of the reactances of the going conductors by three gives the average going reactance per conductor and dividing this average by three (since it is assumed that only one-third of the current went through each conductor) gives the going circuit reactance. Multiplying this value by two gives the total circuit (going plus return) reactance.

The reactance of each going conductor can be written as follows:

$$X_1 = X_{14} + X_{15} + X_{16} - X_{12} - X_{13}$$
$$X_2 = X_{24} + X_{25} + X_{26} - X_{21} - X_{23}$$
$$X_3 = X_{34} + X_{35} + X_{36} - X_{31} - X_{32}$$

with ten per cent voltage drop, as the chances of three simultaneous welds occurring oftener than once per hour is rather remote. (For exceptions see last paragraph.) It should be remembered that these considerations apply only to the large machines. Innumerable small machines can be served from the same transformer bank and bus system along with the five or ten large machines, upon which the distribution system design is based, without any further consideration except that of thermal carrying capacity of the system.

It might not be amiss in this connection to point out another frequently encountered cause of poor welding in addition to that of excessive voltage regulation.

There is a tendency on the part of many users of welding equipment to increase the welding speeds far beyond the capacity of the equipment to make good welds. As a result, a certain percentage of such welds are inferior. The designer then specifies a greater number of welds in an attempt to assure himself of a sufficient number of good welds to produce a satisfactory joint. The production department must then make these welds at an even faster rate of speed to maintain costs, resulting in an even greater number of inferior welds.

This vicious circle of events can be eliminated by insistence upon good welding throughout, resulting in fewer welds per joint, which in turn permits welding speeds commensurate with good welding. This results in better voltage regulation by reducing the chances of simultaneous or interfering welds on any given feeder line.

There may be some classes of welding where every weld must be perfect and there must be no chance of even a few undetected poor welds passing inspection. In these cases it may be desirable to design for closer regulation. However, even under these conditions, the extra investment needed for reduced regulation should be balanced against the cost of necessary recorders and indicators for detecting welds made under improper conditions of voltage, current, and time. It might be more economical to invest in the recorders and indicators than in excessive feeder and transformer capacity which would only be needed once or twice a day when three or more machines might happen to hit together.

Example. Ten 300-kva machines, each machine producing 100 welds per hour of 10 cycles duration each:

$$T = \frac{60 \times 60 \times 60}{100} = 2{,}160 \text{ cycles}$$

$$t = 10 \text{ cycles}$$

$$E = 10 \text{ machines}$$

$$\frac{T}{tE} \times \frac{T}{t(E-1)} = \frac{2{,}160}{10 \times 10} \times \frac{2{,}160}{10 \times 9} = 518 \text{ welds}$$

between operations in which two machines make a weld at the same time.

Total output = 1,000 per hour

Two welds together every (518 × 60)/1,000 = 31 minutes

$$\frac{T}{tE} \times \frac{T}{t(E-1)} \times \frac{T}{t(E-2)} = \frac{2{,}160}{10 \times 10} \times \frac{2{,}160}{10 \times 9} \times \frac{2{,}160}{10 \times 8} = 14{,}000 \text{ welds}$$

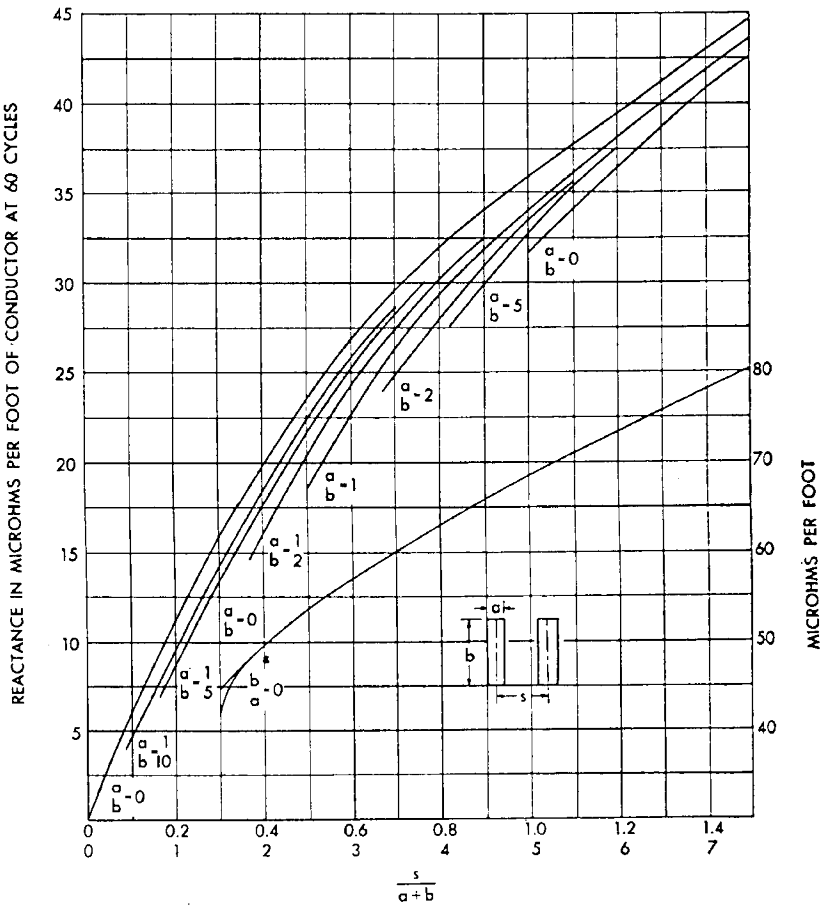


FIG. 32—*Reactance of strap conductors at 60 cycles.*

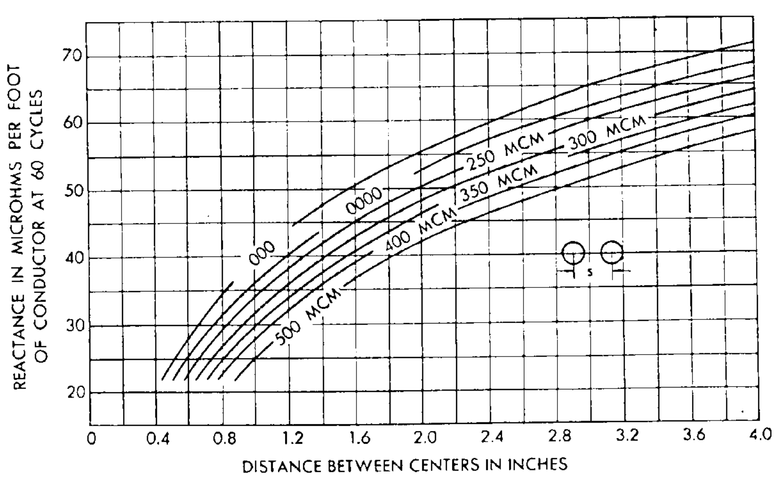


FIG. 33—*Reactance of standard strand cables at 60 cycles.*

The total circuit reactance (going plus return) is:

$$X_T = \frac{2}{9}(X_1 + X_2 + X_3)$$

It should be pointed out that, although this method is approximate, it is accurate within ten per cent which is good enough for most practical calculations.

Numerical Example 1. Determine the reactance of an interlaced bus 1,000 feet long, consisting of ¼ inch by 4 inch copper bars spaced one-inch center-to-center as shown in Table 10, item 15. The distance between the center lines of each conductor and all of the other conductors should be calculated and the reactances corresponding to these distances should be obtained from Figure 32.

For example, the distance between the center lines of conductors 1 and 4 is

$$1'' \times \frac{S}{a + b} = \frac{1''}{\frac{1}{4}'' + 4''} = 0.235$$

and the corresponding reactance is 0.0125 ohm per 1,000 feet. The remaining reactances can be found in a similar manner.

$$X_1 = 0.0125 + 0.0290 + 0.0392 - 0.0220 - 0.0347 = 0.0240$$
$$X_2 = 0.0125 + 0.0125 + 0.0290 - 0.0220 - 0.0220 = 0.0100$$
$$X_3 = 0.0290 + 0.0125 + 0.0125 - 0.0347 - 0.0125 = -0.0027$$

$$X_T = \frac{2}{9}(X_1 + X_2 + X_3) = \frac{2}{9}(0.0249 + 0.0100 - 0.0027) = 0.00696 \text{ ohm}$$
(going and return)

The same method can be used on stranded cables, except that the reactance values are taken from Figure 33.

Numerical Example 2. Determine the reactance of six 250,000-circ-mil interlaced standard-strand, rubber-insulated cables 1,000 feet long and arranged similar to item 8, Table 9, arranged as follows:

(+1) (−4) (+2) (−6) (+3) (−5)

The copper diameter is 0.576 inch, the rubber thickness is 0.094 inch, and the braid thickness is 0.020 inch, giving a total diameter of 0.804 inch. The distance between the center lines of each conductor and all of the other conductors should be calculated and the corresponding reactances should be obtained from Figure 33.

The distance between the center lines of conductors 1 and 3 is $\sqrt{0.804'' + 0.804''} = 1.138$ inches and the corresponding reactance is 0.0368 ohm per 1,000 feet. The remaining reactances can be found in a similar manner.

$$X_1 = 0.0288 + 0.0288 + 0.0473 - 0.0448 - 0.0368 = 0.0233$$
$$X_2 = 0.0288 + 0.0473 + 0.0288 - 0.0448 - 0.0368 = 0.0233$$
$$X_3 = 0.0288 + 0.0288 + 0.0288 - 0.0368 - 0.0368 = 0.0128$$

$$X_T = \frac{2}{9}(X_1 + X_2 + X_3) = \frac{2}{9}(0.0233 + 0.0233 + 0.0128) = 0.0132 \text{ ohm}$$
(going and return)

The reactance of concentric tubular busses is easily expressible in a formula. Let the outer radius of the outer tube be r_4, the inner radius of the outer tube be r_3, the outer radius of the inner tube be r_2, and the inner radius of the inner tube be r_1. The reactance then can be expressed as:

$$X = 11.49\left[4.606\left(\log_{10}\frac{r_3}{r_2} + \frac{r_1^4}{(r_2^2 - r_1^2)^2}\log_{10}\frac{r_2}{r_1} + \frac{r_4^4}{(r_4^2 - r_3^2)^2}\log_{10}\frac{r_4}{r_3}\right) - \frac{r_2^2 + r_1^2}{2(r_2^2 - r_1^2)} - \frac{r_4^2 + r_3^2}{2(r_4^2 - r_3^2)}\right] \times 10^{-3}$$

where X is in ohms per 1,000 feet of bus (total going and return circuit).

Feeder Data for Small Installations

In cases of small installations of welders served at low voltage (240 or 480 volts) by the power company the plant wiring will generally consist of wires pulled in conduit. It is usually unnecessary to lace the going and return wires together for minimum spacing before pulling in conduit, as the natural positioning of the wires in the conduit will give close enough spacing.

The following Table 12 gives the impedances of circuits and current-carrying capacities of relatively small wires suitable for small installations.

TABLE 12—*Impedance and Carrying Capacity of Conductors in One Conduit.*

Wire Size	Conduit Size	Resistance One Conductor Per 1,000 Feet (Ohm)	Reactance One Conductor Per 1,000 Feet (Ohm)	Current-Carrying Capacity (Amperes) Copper, 60° C. Ambient 30° C.
2	1¼	0.156	0.040	107
0	1½	0.098	0.041	139
2/0	2	0.078	0.038	160
3/0	2	0.062	0.036	182
4/0	2	0.049	0.038	210

TYPICAL EXAMPLES

Example 1. Small Job-Welding Shop Machines:
One 150 kva seam welder
Four 20-kva spot welders

Maximum kilovolt-ampere load swing of largest machine:
1,500 amperes at 240 volts = 360 kva

Regulation for 360 kva:	Per Cent
1. Supply system (4,800 volts)	3.0
2. 200 kva, single-phase, 4,800/240-volt, 3-per-cent, Z transformer	5.5
3. 100 feet two 4/0 wires per leg in conduit	2.3
Total	10.8

Equivalent continuous thermal loading:
0.7 × 150 kva = 105
0.1 × 4 × 20 kva = 8

113 kva = 470 amperes at 240 volts

Example 2. Small Job-Welding Shop Machines:
Three 50 kva spot welders
Two 150 kva press welders
One 200 kva projection welder

Maximum kilovolt-ampere load swing of largest machine:
2,100 amperes at 240 volts = 500 kva

Regulation for 500 kva:	Per Cent
1. Supply system (4,800 volts)	4.1
2. 500 kva, single phase, 4,800/240-volt, 3 per cent, Z transformer	2.9
3. 150 feet one ¼ inch by 4 inch bar per leg, 1 inch centers	3.7
Total	10.7

Equivalent continuous thermal loading:
10 per cent × 650 kva = 65 kva = 270 amperes at 240 volts.

Example 3. Small Manufacturing Plant Machines:
Five 250 kva press welders
Two 50 kva spot welders
Eight 30 kva spot welders

Maximum kilovolt-ampere load swing of largest machine:
825 amperes at 485 volts = 400 kva

Regulation for 400 kva:	Per Cent
1. Supply system (24,000 volts)	1.1
2. 700 kva, single-phase, 24,000/485-volt, 13 per cent, Z transformers	7.4
3. 150 feet one ¼ inch by 2″ bar per leg, 2¼ inch centers	2.0
Total	10.5

Equivalent continuous thermal loading:
Practically all three-cycle welding so use about five per cent of sum of connected load 0.05 × 1,590 kva = 80 kva = 165 amperes at 485 volts

Example 4. Small Manufacturing Plant Machines:
Two 150 kva projection welders (automatic feed)
One 75 kva spot welder
One 50 kva spot welder
Eleven 25 kva portable welders

Maximum kilovolt-ampere load swing of largest machine:
850 amperes at 240 volts = 205 kva

Regulation for 205 kva:	Per Cent
1. Supply system (4,800 volts)	2.7
2. 600 kva, three-phase, 4,800/240-volt, 5 per cent, Z power transformer bank	3.4
3. 170 feet two 4/0 wires per leg in conduit	2.6
Total	8.7

Equivalent continuous thermal loading:
150 kva projection welder
2,000 welds per hour – 3-cycle welds
Duty cycle = (2,000 × 3)/(60 × 60 × 60) = 2.77 per cent
200 kva at 2.77 per cent duty cycle = 34 kva continuous
Two machines = 2 × 34 = 68 kva continuous
Remaining machines, 10 per cent × 400 = 40 kva
Total 108 kva

Example 5. Large Manufacturing Plant. Location A. Connect to Phase AB Machines:
Three 550 kva butt welders

One 500 kva projection welder
One 400 kva projection welder
Three 150 kva projection welders

Maximum kilovolt-ampere load swing of largest machine:
2,700 amperes at 480 volts = 1,300 kva

Regulation for 1,300 kva:	Per Cent
1. Supply system (4,800 volts)	5.6
2. Three 500 kva, single-phase, 4,800/480 volt, 3½ per cent, Z transformers	3.0
3. 125 feet two ¼ inch by 4 inch bars per leg, interlaced 2¼″ centers	1.7
Total	10.3

Equivalent continuous thermal loading:
550 kva butt welder
200 welds per hour – 30-cycle welds
Duty cycle = (200 × 30)/(60 × 60 × 60) = 2.77 per cent
1,300 kva at 2.77 per cent duty cycle = 216 kva continuous
Three machines = 3 × 216 = 648 kva continuous
Remaining machines, 10 per cent × 1,350 = 135 kva
Total, 783 kva = 1,670 amperes at 480 volts
Location B. Connect to Phase BC Machines:
40 hydromatic welders, 150 to 300 kva each
Total connected load = 7,000 kva

Maximum kilovolt ampere load swing of largest machine:
2,100 amperes at 480 volts = 1,000 kva

Regulation for 1,000 kva:	Per Cent
1. Supply system (4,800 volts)	4.1
2. Two 500 kva, single-phase 4,800/480 volt, 3½ per cent, Z transformers	3.5
3. 200 feet two ¼ inch by 4 inch bars per leg, interlaced 2¼ inch centers	1.9
Total	9.5

Equivalent continuous thermal loading:
15 per cent × 7,000 kva = 1,050 kva = 2,200 amperes at 480 volts

Location C. Connect to Phase CA Machines:
Two 700 kva butt welders
Two 500 kva butt welders

Maximum kilovolt-ampere load swing of largest machine:
3,500 amperes at 480 volts = 1,670 kva

Regulation for 1,670 kva:	Per Cent
1. Supply system (4,800 volts)	6.9
2. Three 500 kva, single-phase 4,800/480 volt, 3½ per cent, Z transformers	4.0
3. 150 feet two double ¼ inch by 3″ bars per leg, interlaced 3 inch centers	3.1
Total	14.0

The two 700 kva machines were interlocked so that they could not be operated together and the two 500 kva machines were also interlocked.

Equivalent continuous thermal loading:
700 kva welder
100 welds per hour – 2½ second welds
Duty cycle = (100 × 2½ × 60)/(60 × 60 × 60) = 6.95 per cent
1,670 kva at 6.95 per cent duty cycle = 440 kva
Two machines = 2 × 440 = 880 kva
500 kva welder
100 welds per hour – 2 second welds
Duty cycle = (100 × 2 × 60)/(60 × 60 × 60) = 5.55 per cent
1,200 kva at 5.55 per cent duty cycle = 283 kva
Two machines = 2 × 283 = 566 kva
Total 880 + 566 = 1,446 kva