

# **Kanthal® Super Electric heating elements**



**Control, power supply and wiring**

**KANTHAL**

# Content

## Control, power supply and wiring

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# Control, power supply and wiring



### MATERIAL CHARACTERISTICS

Kanthal® Super has two basic material properties that call for special attention when designing the control system.

1. The resistivity increases steeply with temperature (see resistivity curve in the diagram on page 8 in *Part I: Products and accessories*, “Resistivity of Kanthal Super”). The resistance of an element at 20°C is about 11 times lower than the resistance of the same element at 1500°C (2730°F). Hence, if full voltage is applied when starting, a peak current of 11 times the nominal current will flow through the element. This would cause fuse blowing or thyristor failure.
2. The material is brittle at low temperature which means that excessive amperage may cause electromagnetic forces large enough to fracture the element.

### CONTROL IN GENERAL

The low cold resistivity of Kanthal Super implies that full operational voltage cannot be applied to a cold furnace.

In the past, only tapped transformers were available, allowing a reduced voltage to be applied when the furnace was cold, and then the voltage was gradually increased as the elements heated up, thus maintaining currents within manageable levels.

With the advent of modern thyristor (SCR) power control units and the various feedback control features available today, we now have a reasonably economical and reliable means of limiting the start-up currents and taking full advantage of the rapid heat-up capability of Kanthal Super.

Today furnaces equipped with Kanthal Super elements are controlled in the following ways:

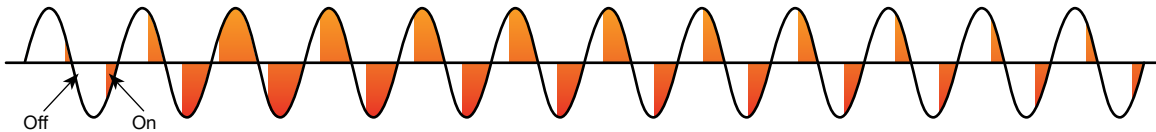
#### Thyristor control

1. Phase-angle fired thyristors with or without a transformer.
2. Burst fired thyristors with phase-angle start with or without a transformer.

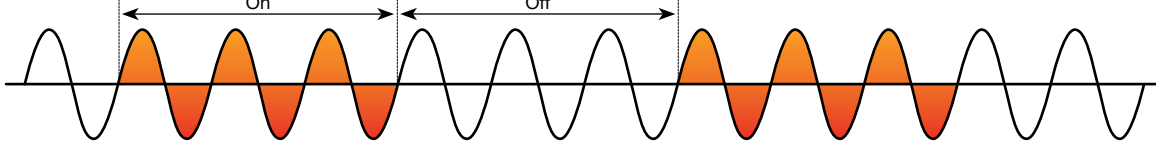
#### On/off control

3. Tapped transformer.
4. Contactor switch, changing the element connection.

a) Phase-angle firing



b) Burst firing



c) Burst firing with phase-angle start

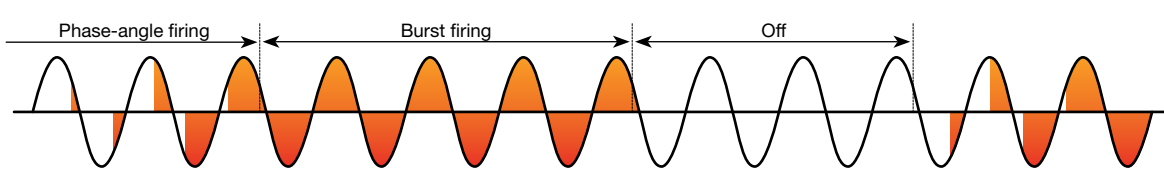


Fig. 1 Thyristor firing modes.

## THYRISTOR CONTROL

### Phase-angle firing

In phase-angle firing the power is controlled by allowing the thyristors to conduct for a part of the AC cycle only (see fig. 1a). The thyristor should have a current ramp turn on function and a RMS (root mean square) current limit facility. It should be noted that this is not the same as the ramp function of the temperature controller.

The thyristor starts to conduct with a small conduction angle and then it increases towards maximum conduction during a number of periods. The more power needed, the larger part of the sinusoid is allowed to pass through the thyristors. If maximum permitted current is attained before full wave, the current limit facility does not permit further increase of the conduction angle.

It is essential that the current is both measured and limited in the RMS method. The reason for this is that in phase-angle firing, one is working with distorted current wave forms, and then the RMS method of current measuring is the only way to obtain a correct and meaningful value.

The ramp turn on function is required for the thyristor to work properly and gives the current limit function time to work.

The main disadvantage of phase-angle firing is that it generates radio frequency interference that may cause malfunction in sensitive electronic equipment.

### Burst firing with phase-angle start

In burst firing the power is controlled by allowing the thyristors to be conductive for one or more complete cycles and then non-conductive for one or more cycles. The higher the power needed, the more conductive cycles and the fewer non-conductive there are (see fig. 1b).

A burst fired thyristor switches on and off when the instantaneous current is zero and therefore creates less transients than non-synchronized equipment.

A usual method of dealing with the disadvantages of phase-angle firing and burst firing is to use a combination of them (see fig. 1c). Phase-angle firing is used during the heating up of the furnace so that the current can be sufficiently limited without using a step-down transformer with different voltage taps. When the furnace reaches a preset temperature below furnace temperature, at least at 600–800°C (1110–1470°F), an automatic switch is turned to burst firing mode. In this way negligible radio frequency interference is created once the furnace is hot.

Fig. 2 and 3 on pages 3–4 show applications with thyristor control.

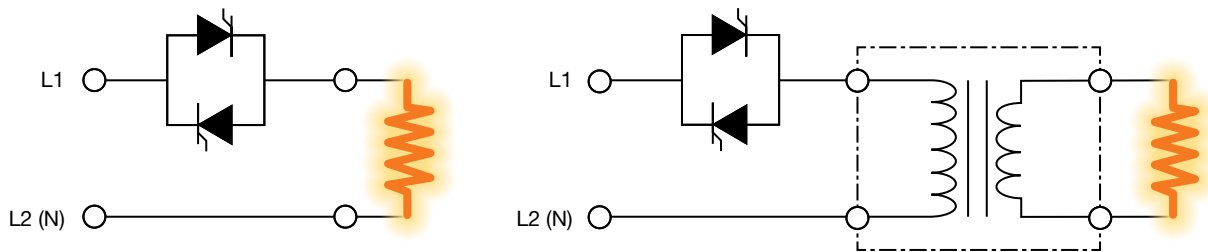
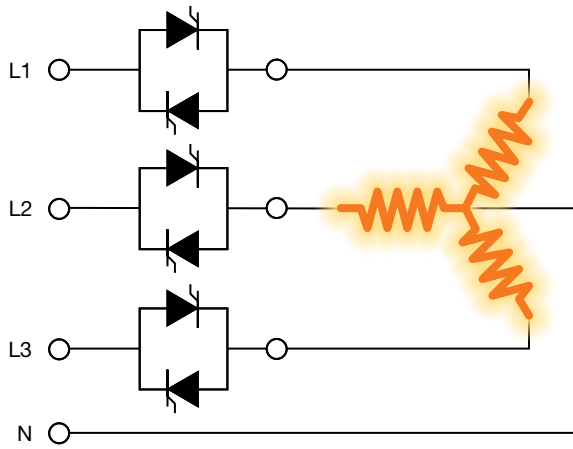
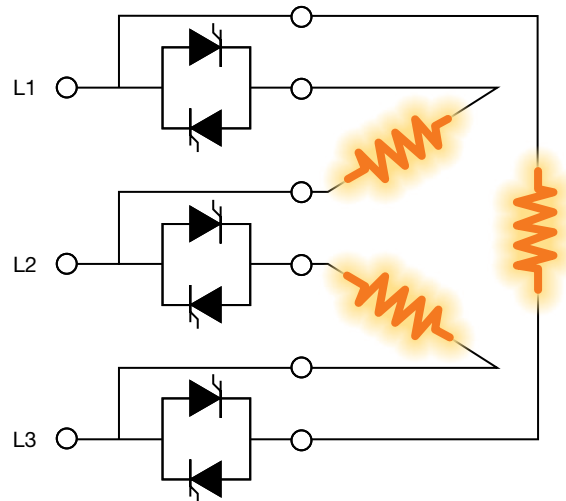


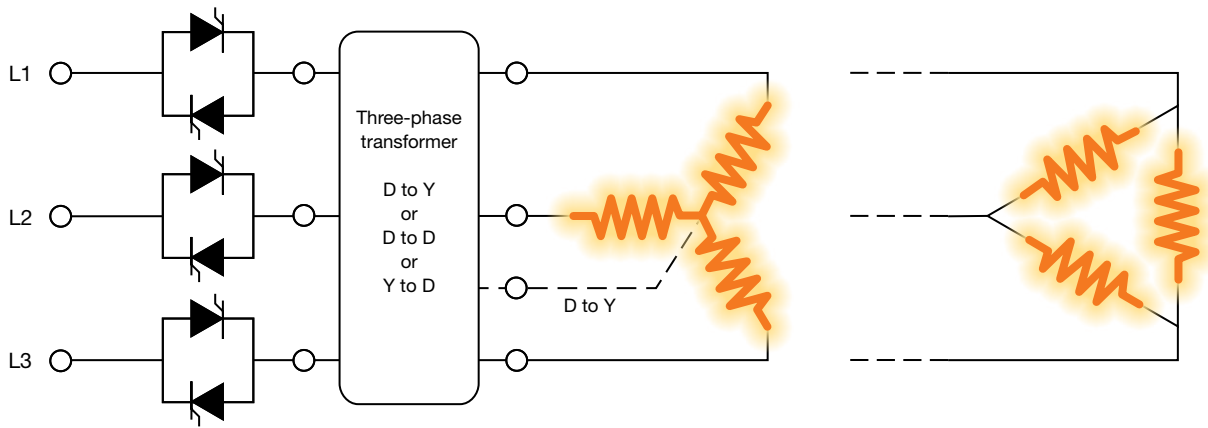
Fig. 2 Single-phase applications with thyristor (SCR) control.



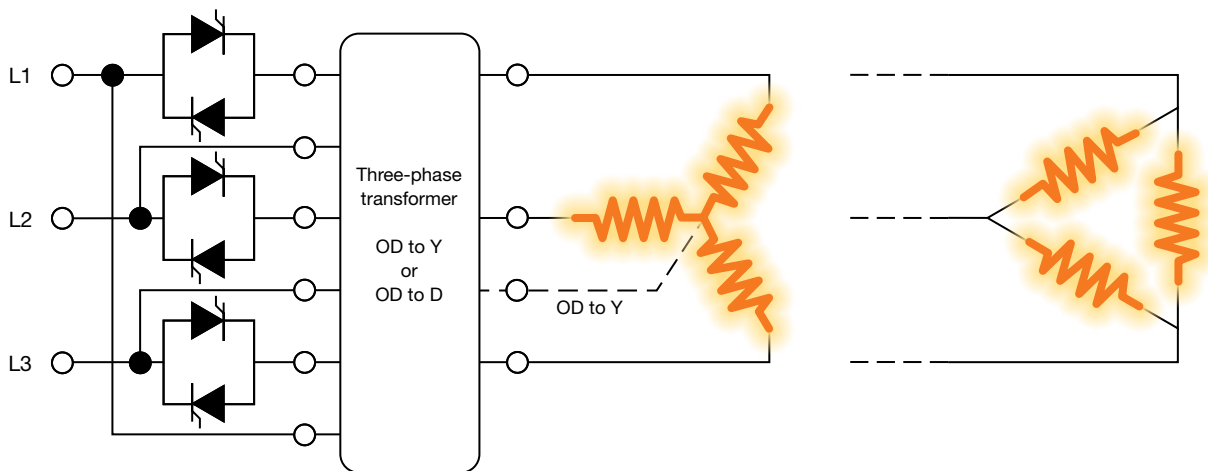
a. Four-wire star.



b. Three-wire open delta.



c. Transformer and star or delta load.



d. Six-wire open delta with transformer and star or delta load.

Fig. 3 Three-phase applications with thyristor (SCR) control.

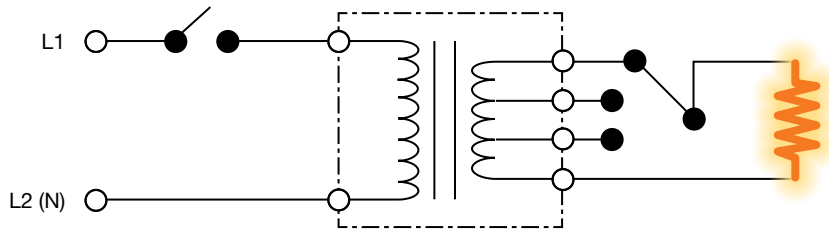
## ON/OFF CONTROL

### Tapped transformer

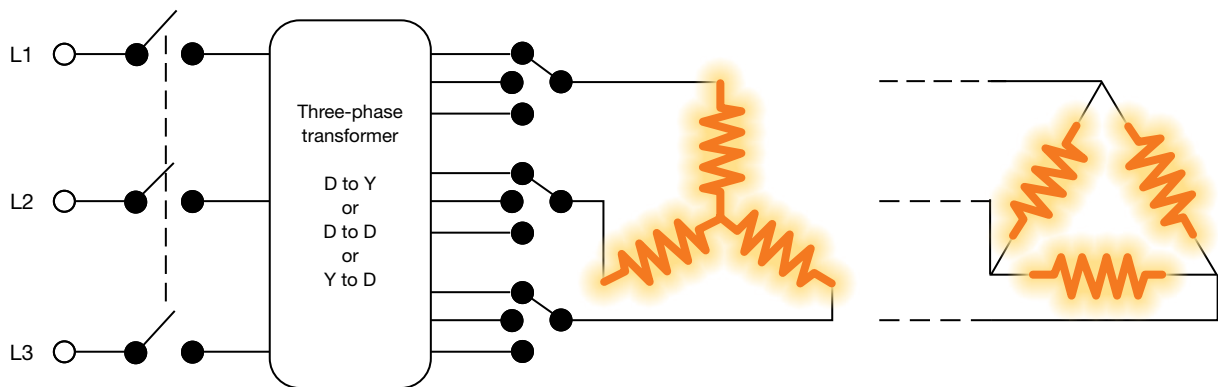
Controlling a furnace with Kanthal® Super elements by a contactor regulated on/off system and a tapped transformer has some disadvantages compared to thyristor control. The main disadvantages are longer on/off periods, which results in less accuracy in temperature control and non-synchronized switching, which means that it creates more transients. There is also mechanical wear on the contactor.

Transformers for stepless voltage regulation are sometimes used to provide accurate control of the energy input in line with the actual requirement.

Fig. 4 below, shows applications with on/off control and tapped transformer.



a. Transformer, single-phase application.



b. Transformer and star or delta load, three-phase application.

Fig. 4 Applications with on/off control.

### Contactor switch, changing the element connection

Fig. 5 on page 6 shows a wiring diagram with the elements star-connected to line voltage. By series-connecting all elements between one phase and neutral, the starting voltage is reduced to 33% of full operating voltage. The intermediate step is to connect the elements in series between two phases, which corresponds to 58% of operating voltage. Finally, the elements are switched to star connection.

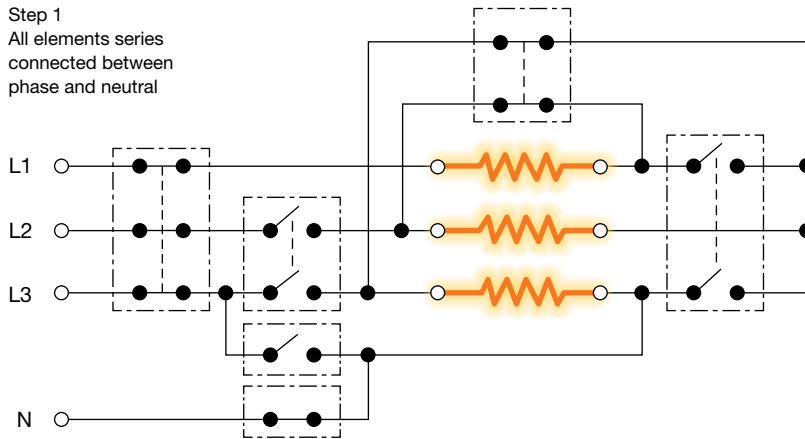
Fig. 6 on page 6 shows a wiring diagram with the elements delta-connected to line voltage. By series-connecting all elements between two phases, the starting voltage is reduced to 33% of full operating voltage. The intermediate step is to connect the elements in star, which corresponds to 58% of operating voltage. Finally, the elements are switched to delta connection.

At start-up, all elements can also be series-connected between one phase and neutral and the starting voltage is reduced to 19% of full operating voltage.

**Directly star-connection to line voltage**

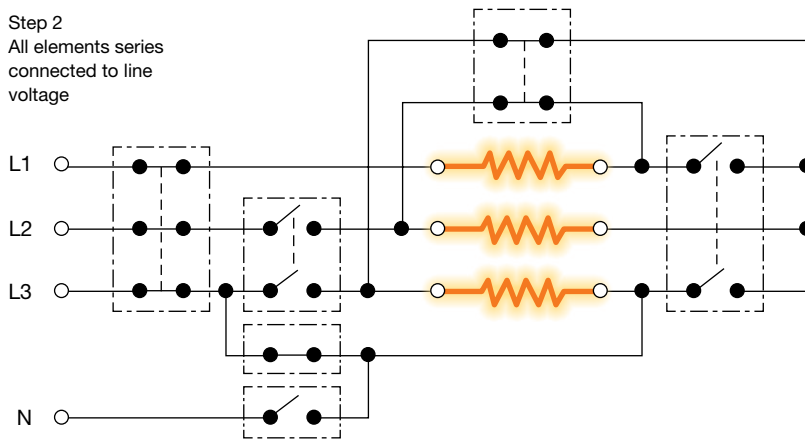
Step 1

All elements series connected between phase and neutral



Step 2

All elements series connected to line voltage



Step 3

Elements star-connected

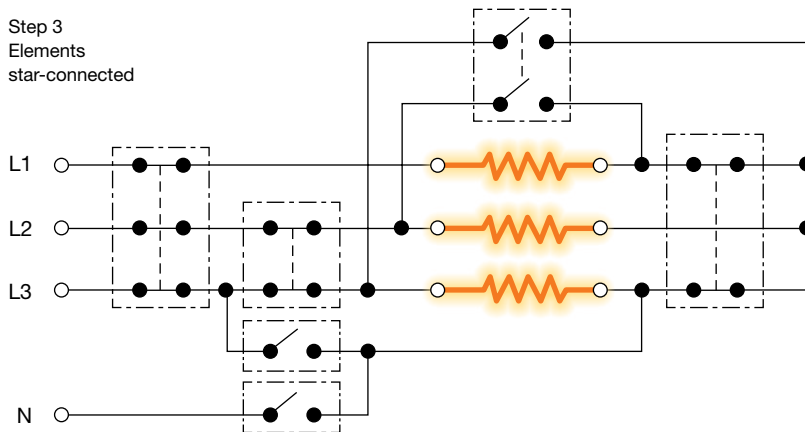


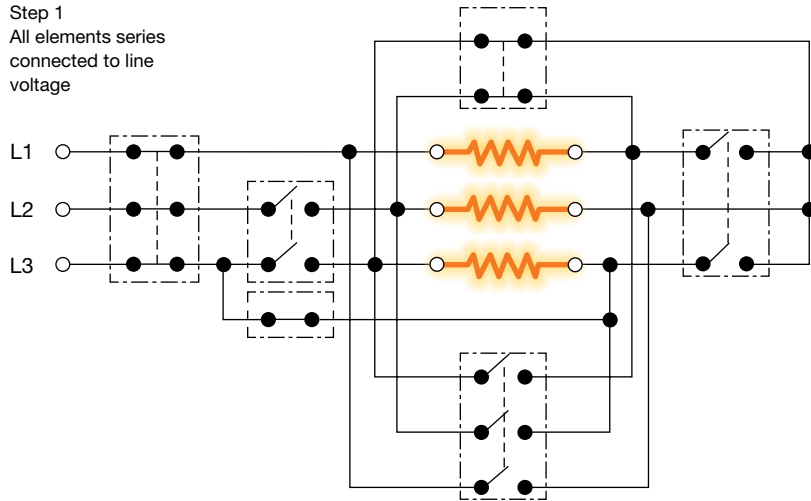
Fig. 5 Wiring diagram for Kanthal® Super elements directly star-connected to line voltage.



**Directly delta-connection to line voltage**

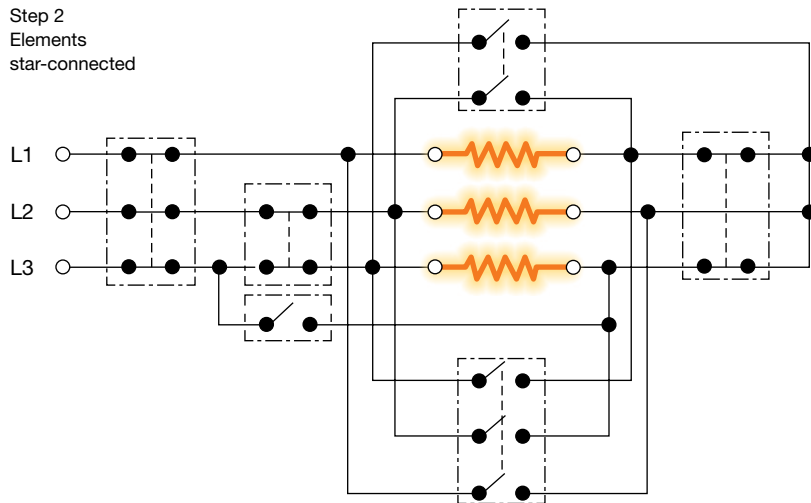
Step 1

All elements series connected to line voltage



Step 2

Elements star-connected



Step 3

Elements delta-connected

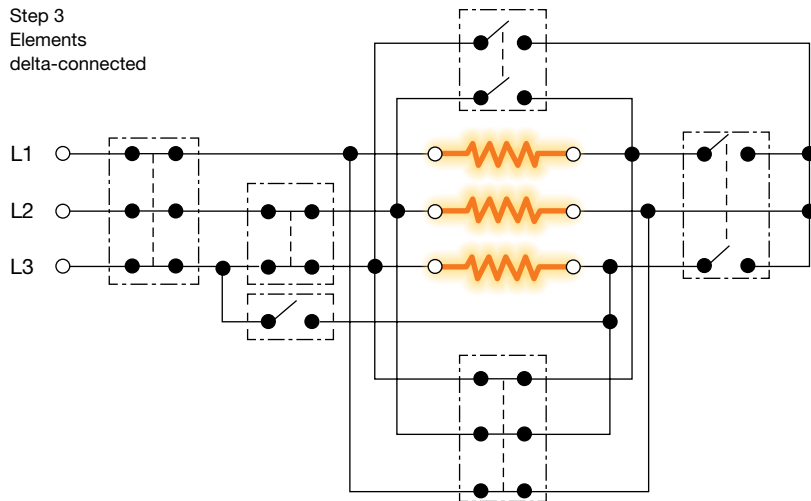


Fig. 6 Wiring diagram for Kanthal Super elements directly delta-connected to line voltage.

### SCOTT-CONNECTED TRANSFORMERS

When the number of elements is such that a symmetrical three-phase load on the secondary side of the transformer is not possible e.g. 4, 8, 10, 14 etc. and yet prefer a symmetrical three-phase load on the primary side a scott-connected transformer should be used.

When the load is equal on the two secondary windings, the primary side will be symmetrically loaded. The two secondary phases are electrically displaced by  $90^\circ$ .

**Note:**

Scott-connections with thyristor control require particular attention for successful operation. Consult Sandvik for advice.

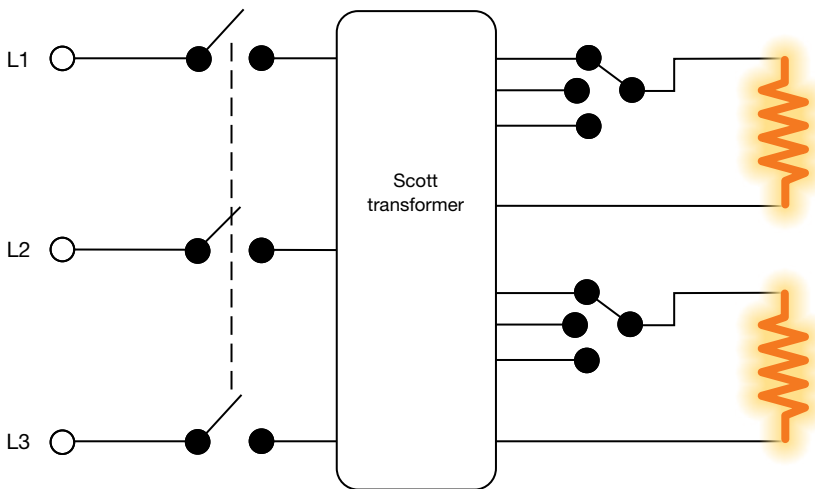


Fig. 7 Application with on/off control and tapped transformer.

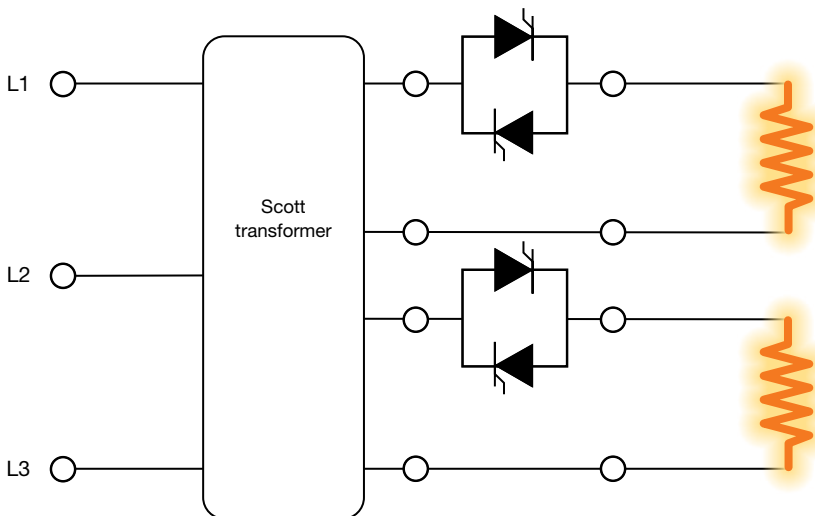


Fig. 8 Application with thyristor control.

## CALCULATION OF TRANSFORMERS

### Thyristor control

When a transformer is used in combination with thyristor control, it must be designed for working with thyristors. The main difference is that larger iron cores are needed than when using on-off control. The reason for this is to obtain a lower magnetic flux density through the core.

Typical values of flux density are for:

On/off controlled transformers: 1.6 T (Tesla)

Transformer with phase-angle fired thyristors: < 1.4 T

Transformers for on/off control can be used for phase-angle firing to 80% of their power rating.

The rating of the transformer for thyristor control is calculated in the following way:

1. The furnace power needed is determined.
2. The size of thyristor is decided.
3. The size of transformer is based on the maximum power that the thyristor needs to control. Generally the transformer is rated 10–20% higher than the furnace power.

### On/off control

When a transformer is used in combination with on/off control, it must be designed for the maximum continuous loading.

Generally it is accurate enough to calculate the power at full operating element voltage and the maximum current permitted for the actual element dimension. Maximum continuous element current for different element dimensions is:

Element size:	3/6	4/9	6/12	9/18	12/24
Current, A	75	115	200	365	560

When heating a furnace from room temperature the starting voltage is normally 1/3 or 1/4 of operating voltage to avoid overloading of the electrical equipment. Transformers provided with steps for 1/3, 2/3, or 1/4, 1/2, 3/4, and full operating voltage is utilized.

## WIRING TO COUNTERACT

### ELECTROMAGNETIC FORCES

Current passing through two parallel conductors produces an electromagnetic force between them. If the current flows in the same direction in the two conductors, there is an attracting force and if it flows in the opposite direction there is a repelling force.

Hence, in a two-shank Kanthal® Super element, a repelling force is set up between the two shanks, which leads to an increase in the distance, *a*, between the shanks of the heating zone.

The result of the repelling force and gravitation on the heating zone of a vertically mounted Kanthal Super element means that a state of equilibrium tends to be reached.

The degree of deformation depends on the amperage *I*, the length of the heating zone *L<sub>e</sub>*, and the distance between the shanks *a*.

The diagram “Deformation of Kanthal Super”, page 12 in *Part I: Products and accessories*, shows how to calculate the distances necessary to counteract the effect of electromagnetic force on Kanthal Super elements.

The effect of the repelling force is reduced if the distance between the shanks is increased. It has been found from practical experience that to avoid excessive deformation, the minimum value of, *a*, should not be below the following:

Element size	Minimum <i>a</i>	Normal <i>a</i>
12/24	50 mm (2 in)	80 mm (3.1 in)
9/18	40 mm (1.5 in)	60 mm (2.4 in)
6/12	25 mm (1 in)	50 mm (2 in)
4/9	20 mm (0.8 in)	25 mm (1 in)
3/6	20 mm (0.8 in)	25 mm (1 in)

If two or more elements are installed together, it is important that they are connected in such a way that the current flows in the opposite direction in two adjacent shanks that are placed close together. Theoretically, if

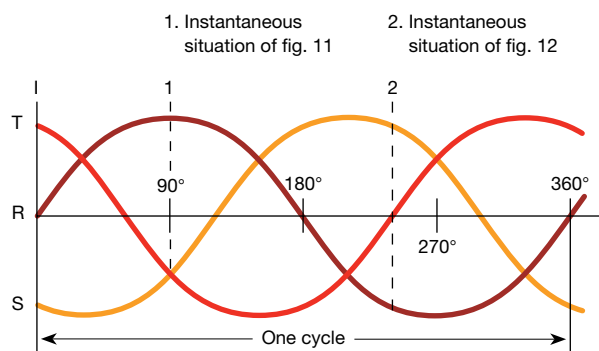


Fig. 9 Sine curve variations in a three-phase system.

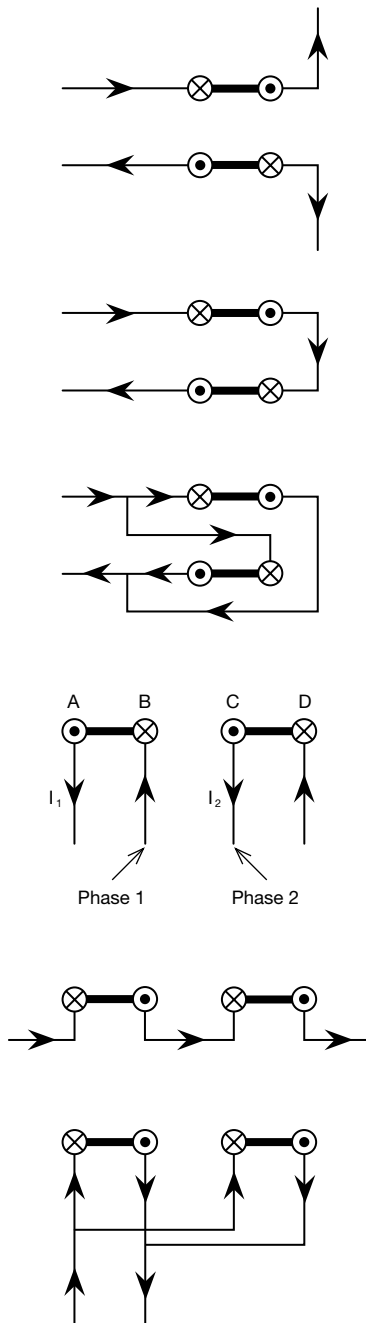
all the repelling effects are of the same magnitude, they balance each other and do not increase the distance between the element shanks. Normally, the distance between adjacent elements is greater than,  $a$ , and consequently the repelling effect between the two shanks of an element will dominate. The result is an increase in,  $a$ .

In the case of element groups connected to a three-phase supply, the connecting points should be combined in such a way that the currents in the adjacent shanks of two Kanthal® Super elements have a phase displace-

ment of  $120^\circ$ . Regardless of the phase displacement, it is always a repelling force which occurs between the two shanks of a Kanthal Super element, and which varies between zero and maximum, see fig. 9.

In fig. 10 "Correct" below, the electromagnetic force between shank "B" (through which a current " $I_1$ " flows) and shank "C" (through which a current " $I_2$ " flows) produces a repelling effect due to the angular displacement between the two phases to which the elements are connected.

**Correct**



**Incorrect**

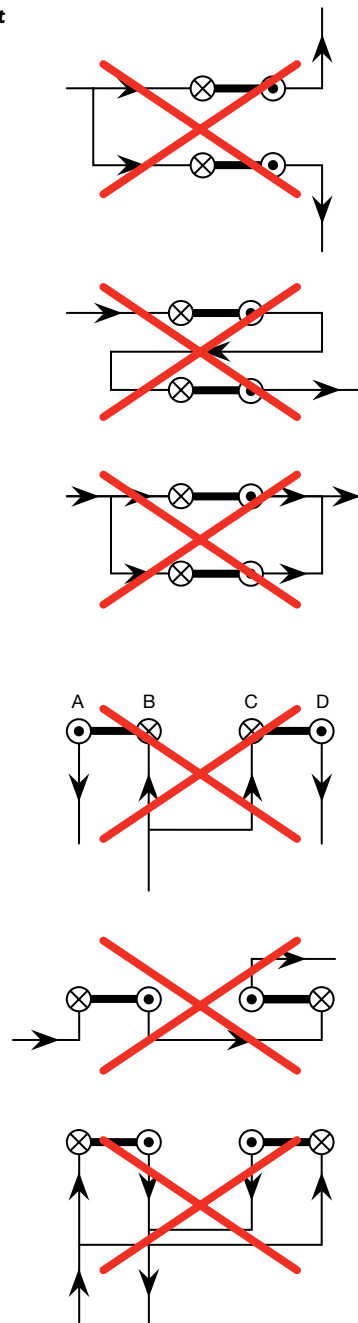


Fig. 10 Examples of correct and incorrect connections.

In three-phase systems the connecting points should be combined in such a way that the currents in the adjacent shanks of two Kanthal Super elements have a phase displacement of  $120^\circ$ . Any other connection should be avoided, since the magnetic force will then have a predominantly attracting effect. This intensifies the effect of the repelling forces acting on the two elements, which can lead to severe deformation.

In order to facilitate the correct connection of Kanthal Super elements to a three-phase supply, bearing in mind that the phases are  $120^\circ$  apart, the current flow directions should be regarded as in fig. 11 and 12 below, as follows:

1. *The current in two phases flow in opposite directions*  
During part of the cycle the currents will flow in the same direction. The maximum attracting effect is obtained when the currents have half the value of the momentary maximum current. The average action, however, is repelling.
2. *Two currents from the neutral point flow in opposite directions*  
The same as under 1. above.
3. *Two currents which come from a common phase connecting point flow in the same direction*

*Remember that two currents from a common phase connection always flow in the same direction. Adjacent elements must never be connected in parallel to the same phase.*

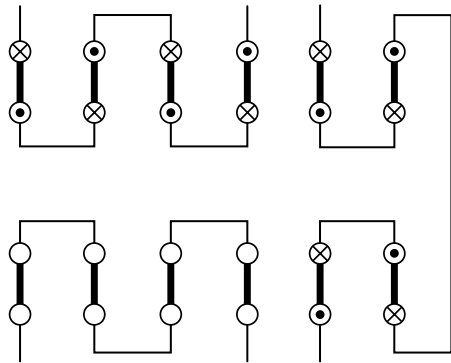


Fig. 11 Delta-connected arrangement.

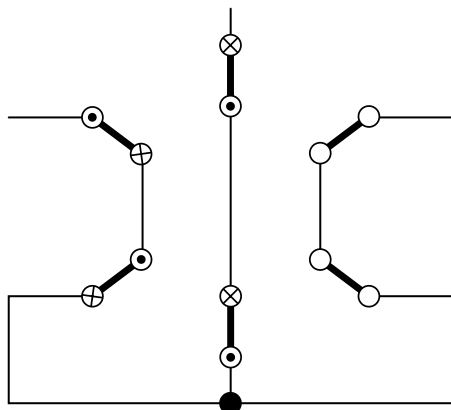
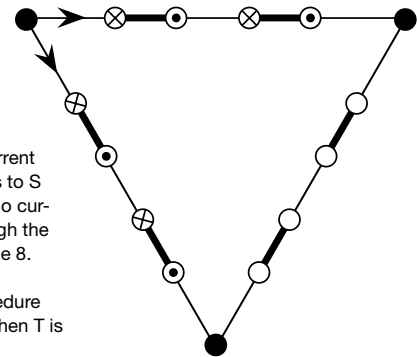
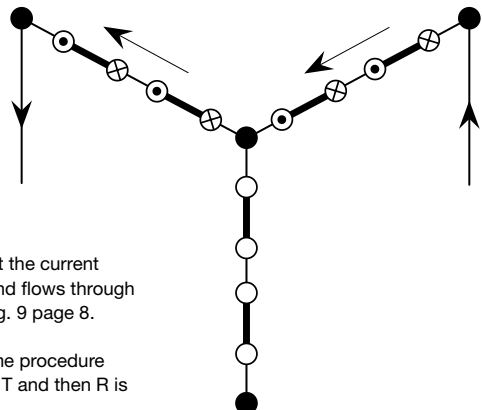


Fig. 12 Star-connected arrangement.



Consider that the current enters in R and flows to S and T. Momentarily no current is passing through the leg ST, see fig. 9 page 8.

Then the same procedure starting from S and then T is followed.



Consider that the current enters in S and flows through 0 to R, see fig. 9 page 8.

Then the same procedure starting from T and then R is followed.



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