TECHNICAL INFORMATION

The following chapter contains practical information on the behaviour, during and after subsequent treatment, of the alloys delivered by Isabellenhütte. This information is intended to assist in selecting the correct alloy for the appropriate application.

As a matter of fact, this information cannot handle all imaginable applications in detail. For special questions, please contact our experts for support.

A collection of the most important and most often used conversion tables concludes this chapter.

A // THE ELECTRICAL RESISTANCE AND ITS TEMPERATURE COEFFICIENT

Resistivity

In accordance with the equation

Eq. 1: $$R_T = \frac{\rho_{el,T} * l}{A}$$

the electrical resistance of a conductor at temperature T is proportional to its length and inversely proportional to its cross-sectional area on the condition that there is a constant cross-section over the whole test length.

R_T = Resistance in Ω at temperature T
l = Length in m
A = Cross-Sectional area in mm²
$\rho_{el,T}$ = Resistivity in Ω * mm² * m⁻¹ at temperature T

In order to calculate

Eq. 2: $$\rho_{el,T} = R_T = \frac{A}{l}$$

R_T, A and l are determined. If

A = 1 mm² and l = 1 m,

are given, one calculates the resistivity in $\Omega * mm^2 * m^{-1}$, i. e. the resistance of a conductor of 1 m length and 1 mm² cross-sectional area.

The resistivity can also be defined as to be the electrical resistance of a cube with 1 cm edge length; then it is expressed in units of Ω * cm. Since for base metals and alloys the resistance of such a cube is very low, the resistance values are expressed in μΩ * cm, i. e. in millionths of an Ω * cm.

The values for e.g. ISOTAN® would then be either
0.49 $\Omega * mm^2 * m^{-1}$ or
49 μΩ * cm

The practical determination of the resistivity can be difficult, since determination of the cross-sectional area of e. g. wires with non-circular cross-section or very thin wires is difficult. In such cases, the cross-sectional area is determined on the basis of weight and length.

The resistivity of a wire can then be determined in accordance with the equation:

Eq. 3: $$\rho_{el,T} = \frac{R_T * m}{\rho_d * l^2}$$

R_T = Resistance in Ω at temperature T
$\rho_{el,T}$ = Resistivity in $\Omega * mm^2 * m^{-1}$ at temperature T
m = Weight in g
ρ_d = Density in g/cm³
l = Length in m

For countries using a different system of measurement the resistivity is expressed in units which must be converted when changing over from one system to another (see Annex "Conversion Values").

Resistance per Meter

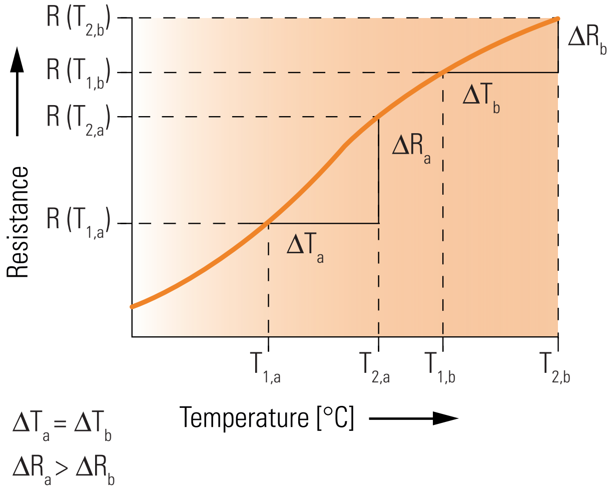
The resistance per meter of a conductor is determined by the quotient of its resistivity and cross-sectional values.

$$\text{Resistance per Meter} = \frac{\text{Resistivity } (\Omega * 1\ mm^2 * m^{-1})}{\text{Cross-sectional area } (mm^2)} = \Omega * m^{-1}$$

The Temperature Coefficient (α or TCR) of Resistivity

Metals and their alloys exhibit a dependence of the resistivity on temperature. In general the resistivity increases with temperature. In a simplified form the temperature dependence of resistivity can be expressed by the equation:

Eq. 4: $$R_{T2} = R_{T1} [1 + \alpha (T_2 - T_1)]$$



Graph 1

This equation applies only if resistance and temperature expose a linear relationship in the test temperature range from T_1 to T_2. For most alloys and metals this is not the case (Graph 1), especially regarding large temperature intervals. In order to deliver an exact description of the temperature dependence of the resistivity, complicated equations are required.

In spite of this the temperature coefficient is defined from the equation above as being:

Eq. 5: $$\alpha_{T1...T2} = \frac{R_2 - R_1}{R_1 (T_2 - T_1)} \qquad [\alpha] = K^{-1}$$

It thus indicates the average variation of the resistivity per degree Kelvin in the temperature range from T_1 to T_2, referred to the resistance value R at T_1.

When experimentally determining the temperature coefficient as well as during communication between supplier and customer, two points must be observed:

1. As already mentioned, the temperature dependence of the resistivity in general does not show a linear, but a curve of a higher-order function. This applies particularly to certain resistance alloys and is the reason why different temperature coefficients result from the calculations, because they depend on the part of the curve which corresponds to a certain Δ T (see table 1).

2. Due to the fact that the temperature-dependent resistance variation is referred to the resistance value R_1 when defining the temperature coefficient, different temperature coefficient values result from different values of R_1, even if the temperature intervals chosen are of equal width. This means that together with the value of the temperature coefficient the temperature interval must always be quoted.

For example
TCR +20 °C to +105 °C = +50 ppm/K

Comparison of test results is possible only if the test conditions are the same. In some alloys the temperature coefficient can be controlled by combining certain alloy components. It can then achieve negative values or values around 0 between room temperature and approx. +100 °C.

Table 1 // **Dependence of Resistivity in µΩ * cm on Temperature for Various Alloys**

Alloy	+20°C	+100°C	+200°C	+300°C	+400°C	+500°C	+600°C	+700°C	+800°C	+900°C	+1,000°C	+1,100°C	+1,200°C
ISAOHM®	132	132	132	-	-	-	-	-	-	-	-	-	-
ISA®-CHROM 60	113[1]	114	116	118	120	122	121	121	122	123	124	126	128
	(111)[2]	(112)	(114)	(116)	(118)	(122)	-	-	-	-	-	-	-
ISA®-CHROM 80	112[1]	113	113	114	115	116	115	114	114	114	115	116	117
	(108)[2]	(109)	(110)	(112)	(114)	(116)	-	-	-	-	-	-	-
ISA®-CHROM 30	104	107	111	114	117	120	122	124	126	128	130	132	-
NOVENTIN®	90	90	-	-	-	-	-	-	-	-	-	-	-
ISOTAN®	49	49	49	49	49	49	-	-	-	-	-	-	-
ISA®-NICKEL	49	51	53	55	56	57	59	60	-	-	-	-	-
MANGANIN®	43	43	-	-	-	-	-	-	-	-	-	-	-
NICKELIN W	40	40.4	41	41.7	42.4	43.2	-	-	-	-	-	-	-
RESISTHERM	33	41	52	64	76	89	102	-	-	-	-	-	-
ISA-ZIN	30	30.4	31	31.5	32.1	32.6	-	-	-	-	-	-	-
ZERANIN® 30	29	29	-	-	-	-	-	-	-	-	-	-	-
ALLOY 127	21	21.5	22.1	22.8	23.4	-	-	-	-	-	-	-	-
ALLOY 90	15	15.6	16.2	16.9	17.5	-	-	-	-	-	-	-	-
ISA® 13	12.5	12.9	13.3	-	-	-	-	-	-	-	-	-	-
ALLOY 60	10	10.7	11.4	12.3	-	-	-	-	-	-	-	-	-
NI 99.2	9	13	19	26	33	38	-	-	-	-	-	-	-
PURE NICKEL	8	12	18	25	32	36	-	-	-	-	-	-	-
SPECIAL NICKEL	7.65	11.1	16.6	-	-	-	-	-	-	-	-	-	-
ALLOY 30	5	5.7	6.4	-	-	-	-	-	-	-	-	-	-
A-COPPER	2.5	3.1	3.9	-	-	-	-	-	-	-	-	-	-
PURE-COPPER	1.72	2.3	3.1	-	-	-	-	-	-	-	-	-	-

1) These values apply to a state of equilibrium.

2) These values apply to a state after rapid cooling; see also B. “Special Characteristics of Nickel-Chromium Alloys”.

B // SPECIAL CHARACTERISTICS OF NICKEL-CHROMIUM ALLOYS

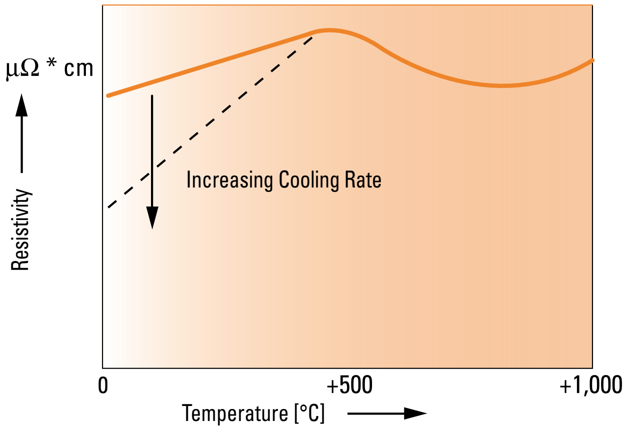
The resistivity of nickel-chromium alloys shows a special characteristic. At temperatures below +500 °C it is affected by the rate with which the alloy has been cooled from high temperatures, e. g. after annealing, and it decreases with increasing cooling rate. This behaviour is shown schematically in the graph on the right.

The solid line represents the so-called state of equilibrium, i. e. the resistivity of an annealed wire after slow cooling. The dotted line indicates how the resistivity below +500 °C changes for lower values by rapid cooling. Rapid cooling takes place e. g. with thin wires after strand annealing.

This effect is strongest for wires of non-ferrous nickel-chromium alloys, like NiCr8020. It is weaker for nickel-chromium NiCr6015 and can be neglected for nickel-chromium NiCr3020.

In addition, since with normal strand annealing the cooling rate increases with decreasing wire diameter, this effect will become stronger, too, as the wire diameter becomes smaller. For NiCr8020 and NiCr6015, assuming normal annealing conditions, the resistance decrease between 1 and 0.01 mm Ø amounts to approx. 1.3 % resp. 0.5 %. For ISAOHM® the decrease amounts to approx. 5 % because of a varying composition.

For resistance wires of NiCr alloys no sliding resistivity has been standardized; instead an average resistivity is quoted (see also DIN 17471). It should be borne in mind, however, that this value for NiCr8020 and NiCr6015 is lower than the value quoted in DIN 17470 for heating resistors.



Effect of Pre-Treatment on the Temperature Dependence of the Resistance on ISA®-CHROM 80 (NiCr8020).

C // SURFACE CURRENT-CARRYING CAPACITY

Generation of heat has great importance in electrical engineering, no matter whether it should be controlled as far as possible or whether it is intended to be used.

The main question to be answered in this connection is what temperature a current-carrying wire, ribbon, sheet etc. will reach during operation.

Answering this question is somewhat difficult, since the determining factors, like type of insulation and shape of the resistive conductor, cooling conditions, surface deterioration during operation and other properties of the material, which for their part again depend on the temperature, can often only be a matter for conjecture.

Current-Carrying Capacity of Wires

In order to make things easier to control, simple models, suitable to be converted into practical solutions, are chosen for tests and measurements. Such a model is formed e. g. by a straight bare wire, stretched in still air of +20 °C, whereby the natural movement of the air is in no way impeded, and which is loaded by current. This model has the advantage that the temperature of the wire can be determined on the basis of its thermal expansion in addition to other methods.

If a current I flows through a conductor with the length l and the resistance R, then the electrical power P, converted into heat, is calculated as follows:

Eq. 6: $P = I^2 * R$

Inserting

Eq. 7: $R = \rho_{el,T} * \frac{l}{A}$

the following results

Eq. 8: $P = \frac{I^2 * \rho_{el,T} * l * 4}{\pi * d^2}$

The amount of heat created per cm² of wire surface is called the surface load n of the wire; it is expressed in Watts (W) per square centimeter (cm^{-2}).

Using the above equation, then after inserting the determining values for the surface in the following results:

Eq. 9: $n = \frac{I^2 * \rho_{el,T} * 0{,}4053}{d^3 * \pi^2}$

n = Surface load in $W * cm^{-2}$
I = Current in Amps
$\rho_{el,T}$ = Resistivity in $\Omega * mm^2 * m^{-1}$ at temperature T (°C)
d = Wire diameter in mm

The surface load is a measure of the temperature the wire will achieve under given environmental conditions. It is not a material-dependent quality, but must be chosen in accordance with the respective conductor material and application.

The upper limit should, of course, be determined on the basis of the maximum working temperature of the conductor in order to ensure adequate scale and corrosion resistance etc.

Fig. 1 shows the relationships between surface load and wire operating temperature for wires of different materials with 0.5 mm Ø.

In general, a current-carrying wire very quickly achieves, after switching-on the current, a stationary state, in which the amount of heat produced within a unit of time equals the amount of heat dissipated. When using the model mentioned above: "Stretched wire in still air of +20 °C", then the heat is dissipated by convection – removal through air flow – and radiation. Under the conditions quoted the heat is removed mainly by convection, while heat removal by radiation is worth mentioning only at temperatures > +400 °C to +600 °C. The share of heat radiation, however, increases with temperature by a factor of T^4.

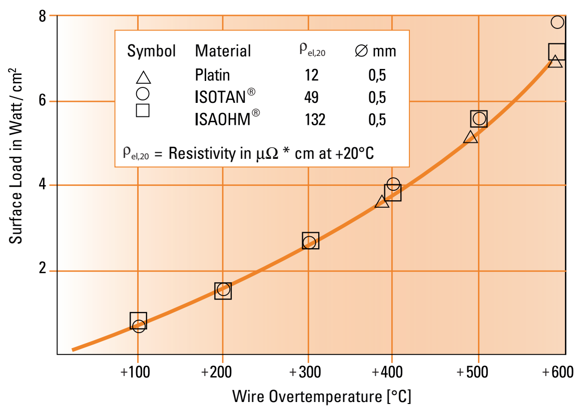


Fig. 1: Overtemperature of Wire against Air in Dependence on the Surface Load in Watt/cm² and on Different Materials.

The diameter of the conductor, too, affects the kind of heat dissipation. Fig. 2 shows the interaction of convection and radiation in dependence on the wire diameter. In the area of the hatched border line heat removal by convection equals that by radiation. At lower temperatures and smaller wire diameters heat removal by convection prevails; at higher temperatures and larger wire diameters heat removal by radiation is in excess.

Fig. 2 shows also that the share of convection in heat dissipation grows with decreasing wire diameter. This is due to the fact that for thinner wires the heat transfer from wire to air improves considerably. In practice this means that, for the same operating temperature, thin wires can be loaded more heavily than thick wires.

By suppressing convection, e. g. by lowering the atmospheric pressure, the curve is shifted to the left; this means that the share of radiation increases. On the other hand the curve can be shifted to the right e. g. by using a fan. Provided the electrical power is kept constant, in the latter case the wire temperature would be substantially lower.

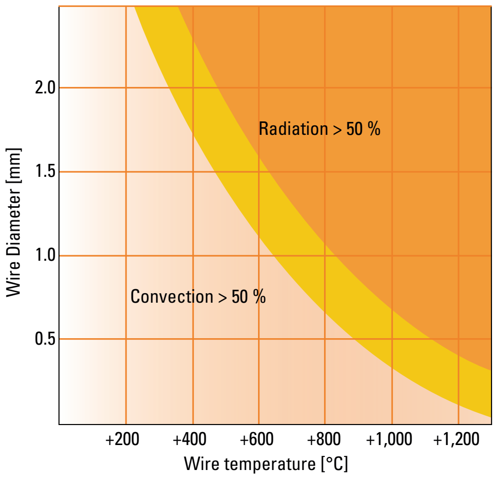


Fig. 2: Comparison of the share of radiation and convection effects in heat dissipation of resistance wires in air at +20 °C. In the dark boundary area heat dissipation by convection about equals that by radiation. On the right of the boundary area radiation prevails; on the left convection has the larger share.

The diagrams mentioned above – figs. 1 and 2 – apply to horizontally arranged straight wires in still air. In practice this arrangement is very rarely chosen, especially for thin wires. Wires wound on cores or arranged in the form of a spiral permit much smaller surface loads since the heat dissipating wire surface is strongly reduced as compared with freely stretched wires. In case of a bobbin being densely wound with resistance wire, the surface of this structure can be taken as the reference quantity for the value "Watt per cm²". This means that the diameter of the wound bobbin can be taken as "wire diameter". The result is that for such a structure at a given surface load in W/cm² the surface temperature will be considerably higher than for a single wire.

Fig. 3 shows the possible current-carrying capacity in Watt/cm² for different temperatures dependent on the "wire" diameter. Bobbins should be referred to in this diagram by the bobbin diameter. Since the current-carrying capacity in Watt per cm² is given, this diagram applies to all Isabellenhütte alloys. The interrelationship between current loads (Amps) and resulting temperature for an ISOTAN® wire of 0.5 mm diam. can be seen from Fig. 4. It must be kept in mind, however, that for this type of presentation the curves for materials with different resistivities are also different, unlike the previous figures.

As shown in fig. 1, a given surface load – expressed in Watt per cm² – causes equal wire temperatures for every alloy. Therefore the current load values for equal wire diameters can be converted by the following formula:

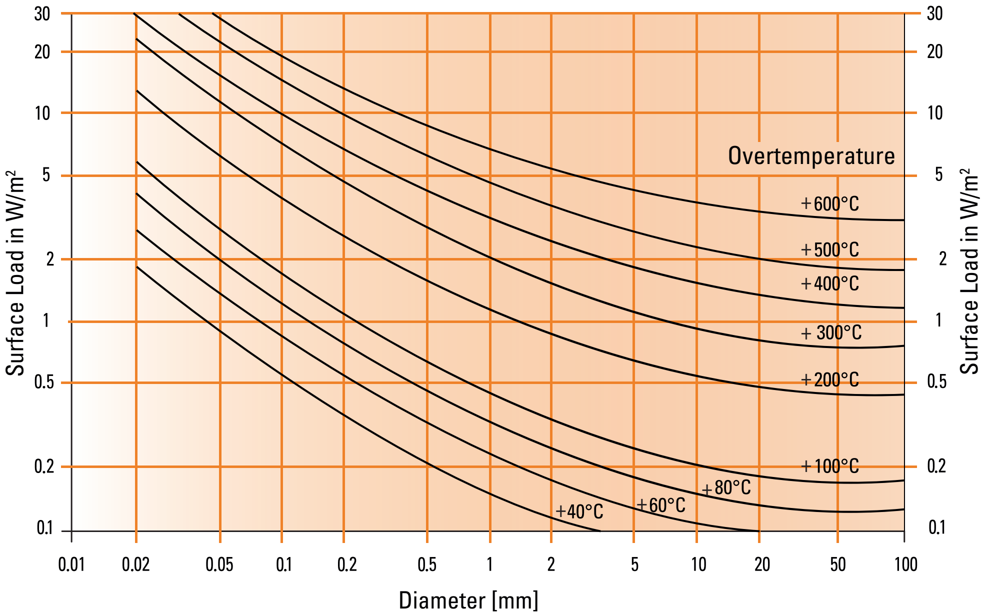


Fig. 3

Eq. 10: $I_1^2 * R_1 = I_2^2 * R_2$

Thus:

Eq. 11: $I_1 = I_2 * \sqrt{\frac{R_2}{R_1}}$

and

Eq. 12: $I_1 = I_2 * \sqrt{\frac{\rho_2}{\rho_1}}$

The following tables show, with ISOTAN® as an example, the geometrical data between 0.02 and 6.3 mm Ø as well as the current-carrying capacity values in Amps for +40/+60/+80/+100/+200/+300/+400/+500 and +600 °C. In accordance with the above formula, the current values are converted in accordance with:

Eq. 13: $I_x = I_{ISOTAN} * \sqrt{\frac{49\ \mu\Omega * cm}{\rho_{el,x}}}$

where I_x refers to the current for a wire of an alloy with the resistivity $\rho_{el,x}$. It must be kept in mind that for $\rho_{el,x}$ the values valid for the respective temperature must be used (see table 2).

The current-carrying capacity tables all refer to bare wire; due to better heat dissipation, oxidized wires (only possible for the alloys ISA®-CHROM 60, ISA®-CHROM 80 and ISOTAN®) can withstand a load increase of up to 20 %, expressed in Watt per cm², mainly at higher temperatures. The current-carrying capacities of enamelled wires are about the same as those of bare wires. The heat insulation effect of the enamel is compensated by the increase of the effective diameter and good heat dissipation properties. Silk-covered wires exhibit strongly varying loading capacities, depending on the kind of manufacturing process and type; the respective value must be determined individually.

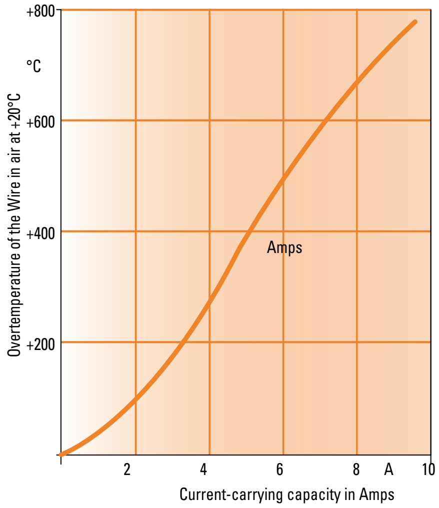


Fig. 4: Current-carrying capacity of ISOTAN® wire of 0.5 mm Ø in dependence on overtemperature of the wire against air at +20 °C (+100 °C overtemperature correspond to a real temperature of +120 °C).

Table 2

Diameter in mm	ISOTAN® Resistance Ohm/m	Amps for an Overtemperature of: +40 °C		+60 °C		+80 °C		+100 °C		+200 °C	
		I in A	Surface Load in W/cm²	I in A	Surface Load in W/cm²	I in A	Surface Load in W/cm²	I in A	Surface Load in W/cm²	I in A	Surface Load in W/cm²
0.020	1,560	0.0270	1.82	0.0342	2.92	0.0410	4.20	0.0479	5.69	0.0724	13.0
0.022	1,290	0.0305	1.75	0.0381	2.74	0.0450	3.82	0.0534	5.31	0.0807	12.1
0.025	998	0.0353	1.60	0.0441	2.49	0.0520	3.47	0.0617	4.84	0.0933	11.1
0.028	796	0.0402	1.48	0.0502	2.30	0.0600	3.29	0.0703	4.46	0.106	10.2
(0.030)	693	0.0437	1.41	0.0546	2.21	0.0650	3.13	0.0764	4.29	0.115	9.70
0.032	609	0.0467	1.33	0.0584	2.08	0.0690	2.90	0.0818	4.05	0.124	9.26
0.036	481	0.0534	1.22	0.0668	1.92	0.0790	2.68	0.0935	3.72	0.140	8.51
0.040	390	0.0606	1.15	0.0757	1.79	0.0900	2.53	0.106	3.45	0.160	7.89
0.045	308	0.0691	1.05	0.0864	1.64	0.102	2.28	0.121	3.17	0.183	7.26
0.050	249	0.0777	0.966	0.0971	1.51	0.115	2.12	0.136	2.94	0.206	6.74
0.056	199	0.0880	0.880	0.110	1.38	0.130	1.92	0.154	2.68	0.235	6.22
(0.060)	173	0.0960	0.853	0.120	1.33	0.142	1.87	0.168	2.58	0.254	5.93
0.063	157	0.101	0.816	0.126	1.27	0.150	1.80	0.177	2.49	0.269	5.73
(0.070)	127	0.114	0.758	0.143	1.19	0.169	1.67	0.200	2.32	0.303	5.33
0.071	124	0.116	0.752	0.145	1.17	0.172	1.65	0.203	2.29	0.308	5.27
0.080	97.5	0.133	0.691	0.166	1.08	0.197	1.52	0.233	2.11	0.354	4.86
0.090	77.0	0.153	0.642	0.191	1.00	0.226	1.40	0.267	1.94	0.406	4.48
0.100	62.4	0.173	0.600	0.216	0.933	0.254	1.29	0.302	1.81	0.458	4.17
(0.110)	51.6	0.193	0.560	0.241	0.873	0.286	1.23	0.337	1.69	0.512	3.91
0.112	49.7	0.197	0.554	0.246	0.865	0.292	1.22	0.345	1.68	0.523	3.86
(0.120)	43.3	0.213	0.524	0.266	0.818	0.315	1.15	0.372	1.59	0.567	3.69
0.125	39.9	0.223	0.510	0.279	0.798	0.331	1.12	0.391	1.55	0.594	3.59
(0.130)	36.9	0.234	0.498	0.292	0.775	0.347	1.09	0.409	1.51	0.622	3.50
0.140	31.8	0.255	0.475	0.319	0.742	0.378	1.04	0.446	1.44	0.679	3.33
(0.150)	27.7	0.276	0.452	0.345	0.706	0.409	0.993	0.483	1.37	0.736	3.18
0.160	24.4	0.297	0.430	0.371	0.671	0.441	0.949	0.520	1.31	0.794	3.05
0.180	19.3	0.342	0.401	0.428	0.628	0.508	0.885	0.599	1.22	0.911	2.83
0.200	15.6	0.386	0.372	0.482	0.581	0.572	0.818	0.675	1.13	1.03	2.64
(0.220)	12.9	0.433	0.354	0.541	0.552	0.642	0.778	0.758	1.07	1.16	2.49
0.224	12.4	0.441	0.347	0.551	0.542	0.653	0.761	0.771	1.05	1.18	2.46
0.250	9.98	0.503	0.324	0.629	0.507	0.746	0.713	0.880	0.982	1.35	2.30
0.280	7.96	0.577	0.303	0.721	0.473	0.856	0.666	1.01	0.914	1.54	2.14
(0.300)	6.93	0.623	0.287	0.778	0.448	0.924	0.632	1.12	0.875	1.67	2.06
0.315	6.29	0.663	0.281	0.828	0.438	0.983	0.612	1.16	0.849	1.77	2.00
(0.320)	6.09	0.672	0.275	0.843	0.433	1.00	0.609	1.18	0.841	1.81	1.98
(0.350)	5.09	0.748	0.261	0.936	0.406	1.11	0.574	1.31	0.796	2.01	1.87
0.355	4.95	0.760	0.258	0.950	0.404	1.13	0.571	1.33	0.789	2.05	1.86
0.40	3.90	0.880	0.242	1.10	0.378	1.31	0.536	1.54	0.734	2.37	1.73
0.45	3.08	1.01	0.224	1.26	0.349	1.50	0.494	1.77	0.684	2.73	1.62
0.50	2.49	1.15	0.212	1.44	0.332	1.70	0.462	2.01	0.644	3.10	1.53
(0.55)	2.06	1.29	0.200	1.61	0.315	1.92	0.444	2.26	0.609	3.49	1.45
0.56	1.99	1.32	0.198	1.65	0.309	1.95	0.432	2.31	0.603	3.57	1.44
(0.60)	1.73	1.43	0.189	1.79	0.297	2.13	0.420	2.51	0.580	3.88	1.39
0.63	1.57	1.53	0.187	1.91	0.292	2.26	0.409	2.67	0.565	4.12	1.35
(0.65)	1.48	1.58	0.182	1.98	0.285	2.35	0.402	2.77	0.555	4.29	1.33
(0.70)	1.27	1.74	0.177	2.17	0.275	2.58	0.388	3.04	0.533	4.70	1.28
0.71	1.24	1.77	0.175	2.21	0.273	2.62	0.383	3.09	0.529	4.78	1.27
0.75	1.11	1.89	0.169	2.36	0.264	2.81	0.374	3.31	0.514	5.12	1.23
0.80	0.975	2.05	0.164	2.56	0.256	3.03	0.359	3.58	0.496	5.55	1.19
0.85	0.864	2.21	0.159	2.76	0.248	3.27	0.348	3.86	0.481	5.99	1.16
0.90	0.770	2.37	0.154	2.96	0.240	3.51	0.338	4.14	0.467	6.43	1.13
0.95	0.691	2.53	0.149	3.16	0.233	3.75	0.328	4.43	0.454	6.89	1.01
1.00	0.624	2.70	0.146	3.37	0.227	4.00	0.320	4.72	0.442	7.35	1.07
(1.10)	0.516	3.04	0.139	3.80	0.217	4.51	0.306	5.32	0.422	8.30	1.03
1.12	0.497	3.11	0.138	3.88	0.215	4.61	0.304	5.44	0.418	8.49	1.02
(1.20)	0.433	3.39	0.133	4.24	0.208	5.03	0.292	5.94	0.405	9.27	0.986
1.25	0.399	3.57	0.131	4.46	0.204	5.30	0.288	6.25	0.397	9.77	0.969
1.40	0.318	4.12	0.124	5.16	0.194	6.12	0.273	7.22	0.377	11.3	0.923
1.50	0.277	4.50	0.120	5.63	0.188	6.68	0.265	7.88	0.365	12.3	0.896
1.60	0.244	4.89	0.117	6.11	0.182	7.25	0.256	8.56	0.355	13.4	0.873
1.80	0.193	5.69	0.110	7.12	0.174	8.43	0.244	9.95	0.337	15.7	0.833
2.00	0.156	6.50	0.106	8.14	0.166	9.66	0.233	11.4	0.323	17.9	0.800
(2.20)	0.129	7.37	0.102	9.21	0.160	10.9	0.224	12.9	0.311	20.4	0.773
2.24	0.124	7.54	0.101	9.43	0.159	11.2	0.222	13.2	0.307	20.9	0.768
2.50	0.0998	8.74	0.098	10.9	0.152	13.0	0.217	15.3	0.296	24.1	0.739
2.80	0.0796	10.1	0.094	12.6	0.144	15.0	0.205	17.7	0.284	28.1	0.712
3.00	0.0693	11.1	0.092	13.9	0.143	16.4	0.199	19.4	0.277	30.7	0.696
3.15	0.0629	11.8	0.089	14.8	0.140	17.5	0.198	20.7	0.272	32.9	0.685
(3.20)	0.0609	12.1	0.089	15.1	0.139	18.0	0.197	21.2	0.271	33.6	0.682
(3.50)	0.0509	13.6	0.086	17.1	0.137	20.2	0.190	23.8	0.263	37.9	0.664
3.55	0.0495	13.9	0.086	17.4	0.135	20.6	0.189	24.3	0.262	38.6	0.661
4.00	0.0390	16.3	0.083	20.4	0.130	24.1	0.181	28.5	0.252	45.4	0.639
4.50	0.0308	19.1	0.080	23.8	0.124	28.3	0.176	33.4	0.243	53.3	0.619
5.00	0.0249	22.0	0.077	27.6	0.122	32.7	0.171	38.6	0.236	61.6	0.602
5.50	0.0206	25.0	0.075	31.3	0.118	37.1	0.166	43.8	0.229	70.3	0.589
5.60	0.0199	25.7	0.075	32.1	0.117	38.1	0.165	44.9	0.228	72.0	0.586
6.00	0.0173	28.2	0.074	35.3	0.115	41.9	0.162	49.4	0.224	79.2	0.577
6.30	0.0157	30.2	0.073	37.8	0.114	44.8	0.161	52.9	0.222	84.8	0.571

Amps for an Overtemperature of:									
+300 °C		+400 °C		+500 °C		+600 °C			
I in A	**Surface Load in W/cm²**	**I in A**	**Surface Load in W/cm²**	**I in A**	**Surface Load in W/cm²**	**I in A**	**Surface Load in W/cm²**	**ISOTAN® Resistance Ohm/m**	**Diameter in mm**
0.0964	23.0	0.110	30.1	0.133	44.2	0.144	51.2	1,560	0.020
u.109	22.2	0.123	28.2	0.149	41.4	0.161	48.3	1,290	0.022
0.124	19.6	0.143	25.9	0.173	38.0	0.188	44.7	998	0.025
0.138	18.1	0.163	24.0	0.197	35.2	0.215	41.7	796	0.028
0.153	17.2	0.177	22.9	0.214	33.7	0.233	40.0	693	(0.030)
0.165	16.4	0.191	22.0	0.231	32.2	0.252	38.5	609	0.032
0.188	15.1	0.219	20.3	0.265	29.8	0.290	35.8	481	0.036
0.212	14.0	0.247	19.0	0.300	27.8	0.329	33.6	390	0.040
0.243	12.9	0.284	17.6	0.344	25.8	0.379	31.4	308	0.045
0.274	11.9	0.321	16.4	0.389	24.0	0.431	29.4	249	0.050
0.312	11.0	0.367	15.2	0.445	22.3	0.494	27.6	199	0.056
0.338	10.5	0.398	14.6	0.482	21.4	0.537	26.5	173	(0.060)
0.358	10.2	0.422	14.1	0.511	20.7	0.569	25.7	157	0.063
0.404	9.43	0.478	13.2	0.578	19.3	0.646	24.1	127	(0.070)
0.411	9.34	0.486	13.1	0.588	19.2	0.658	24.0	124	0.071
0.471	8.60	0.559	12.1	0.677	17.8	0.760	22.4	97.5	0.080
0.540	7.94	0.648	11.4	0.785	16.8	0.877	20.9	77.0	0.090
0.610	7.39	0.728	10.5	0.882	15.4	0.966	19.7	62.4	0.100
0.682	6.93	0.816	9.92	0.985	14.5	1.12	18.7	51.6	(0.110)
0.696	6.84	0.833	9.81	1.01	14.4	1.15	18.5	49.7	0.112
0.754	6.53	0.905	9.40	1.10	13.8	1.25	17.8	43.3	(0.120)
0.791	6.36	0.950	9.16	1.15	13.4	1.31	17.4	39.9	0.125
0.828	6.20	0.995	8.95	1.21	13.1	1.37	17.1	36.9	(0.130)
0.903	5.90	1.09	8.55	1.32	12.5	1.51	16.4	31.8	0.140
0.979	5.64	1.18	8.20	1.43	12.0	1.64	15.8	27.7	(0.150)
1.06	5.40	1.28	7.89	1.55	11.6	1.77	15.3	24.4	0.160
1.21	5.01	1.47	7.35	1.78	10.8	2.05	14.3	19.3	0.180
1.37	4.68	1.67	6.91	2.02	10.1	2.34	13.6	15.6	0.200
1.54	4.41	1.87	6.54	2.27	9.59	2.63	12.9	12.9	(0.220)
1.57	4.36	1.91	6.47	2.32	9.49	2.69	12.8	12.4	0.224
1.79	4.07	2.19	6.07	2.65	8.91	3.08	12.1	9.98	0.250
2.05	3.80	2.51	5.70	3.04	8.35	3.55	11.4	7.96	0.280
2.23	3.64	2.73	5.48	3.31	8.04	3.87	11.0	6.93	(0.300)
2.36	3.54	2.90	5.33	3.51	7.82	4.12	10.8	6.29	0.315
2.41	3.50	2.96	5.29	3.58	7.76	4.20	10.7	6.09	(0.320)
2.68	3.32	3.30	5.04	4.00	7.39	4.70	10.2	5.09	(0.350)
2.72	3.29	3.36	5.00	4.07	7.33	4.79	10.2	4.95	0.355
3.15	3.07	3.89	4.69	4.71	6.87	5.57	9.60	3.90	0.40
3.63	2.87	4.50	4.40	5.45	6.46	6.46	9.09	3.08	0.45
4.13	2.71	5.13	4.17	6.21	6.12	7.39	8.69	2.49	0.50
4.64	2.57	5.77	3.97	6.99	5.83	8.35	8.31	2.06	(0.55)
4.75	2.55	5.91	3.94	7.15	5.78	8.54	8.24	1.99	0.56
5.17	2.45	6.44	3.81	7.80	5.58	9.33	8.00	1.73	(0.60)
5.49	2.39	6.84	3.72	8.29	5.45	9.94	7.83	1.57	0.63
5.70	2.35	7.18	3.66	8.62	5.37	10.3	7.73	1.48	(0.65)
6.26	2.26	7.81	3.53	9.46	5.18	11.4	7.49	1.27	(0.70)
6.37	2.25	7.96	3.51	9.63	5.15	11.6	7.45	1.24	0.71
6.82	2.19	8.53	3.42	10.3	5.10	12.4	7.28	1.11	0.75
7.39	2.12	9.25	3.32	11.2	4.87	13.5	7.09	0.975	0.80
7.97	2.05	9.99	3.23	12.1	4.73	14.6	6.92	0.864	0.85
8.57	2.00	10.7	3.14	13.0	4.61	15.8	6.77	0.770	0.90
9.17	1.95	11.5	3.07	13.9	4.50	16.9	6.62	0.691	0.95
9.78	1.90	12.3	3.00	14.9	4.40	18.1	6.50	0.624	1.00
11.0	1.82	13.9	2.88	16.8	4.22	20.5	6.27	0.516	(1.10)
11.3	1.80	14.2	2.86	17.2	4.19	21.0	6.22	0.497	1.12
12.3	1.75	15.5	2.78	18.8	4.07	23.0	6.07	0.433	(1.20)
13.0	1.72	16.4	2.73	19.8	4.00	24.3	5.98	0.399	1.25
15.0	1.63	19.0	2.61	23.0	3.82	28.2	5.74	0.318	1.40
16.4	1.59	20.8	2.54	25.2	3.72	30.9	5.61	0.277	1.50
17.9	1.55	22.6	2.47	27.4	3.63	33.7	5.49	0.244	1.60
20.8	1.48	26.4	2.37	32.0	3.47	39.4	5.28	0.193	1.80
23.9	1.42	30.3	2.28	36.7	3.34	45.4	5.11	0.156	2.00
27.1	1.37	34.4	2.21	41.7	3.23	51.6	4.96	0.129	(2.20)
27.8	1.36	35.2	2.19	42.7	3.21	52.9	4.94	0.124	2.24
32.1	1.31	40.8	2.11	49.4	3.01	61.4	4.78	0.0998	2.50
37.4	1.26	47.5	2.04	57.4	2.99	71.6	4.63	0.0796	2.80
41.0	1.23	52.1	1.99	63.1	2.93	78.6	4.54	0.0693	3.00
43.7	1.21	55.6	1.97	67.4	2.88	84.1	4.49	0.0629	3.15
44.7	1.21	56.8	1.96	68.8	2.87	85.9	4.47	0.0609	(3.20)
50.4	1.18	64.2	1.91	77.7	2.79	97.1	4.37	0.0509	(3.50)
51.4	1.17	65.4	1.90	79.2	2.78	99.1	4.35	0.0495	3.55
60.4	1.13	76.9	1.84	93.2	2.69	117	4.23	0.0390	4.00
71.0	1.01	90.4	1.78	109	2.61	137	4.11	0.0308	4.50
82.0	1.07	104	1.73	127	2.54	159	4.02	0.0249	5.00
93.7	1.05	119	1.69	144	2.48	182	3.94	0.0206	5.50
95.9	1.04	122	1.69	148	2.47	186	3.92	0.0199	5.60
105	1.02	134	1.60	163	2.44	205	3.87	0.0173	6.00
113	1.01	144	1.64	174	2.41	220	3.83	0.0157	6.30

In the following some examples are given:

Example 1

Problem
What current is required to increase the temperature by +200 °C of ISA® 13 wire with a diameter of 0.20 mm?

Solution

a) From the table can be seen that the value for ISOTAN® wire with equal diameter is 1.03 amps.

b) This value must be converted for ISA® 13 in accordance with the previously quoted formula; this results in

Eq. 14: $$I_x = 1.03\text{ A} * \sqrt{\frac{49\ \mu\Omega * \text{cm}}{13.3\ \mu\Omega * \text{cm}}} = 1.03\text{ A} * 1.92 \approx 2\text{ A}$$

where 49 μΩ * cm is the resistivity of ISOTAN® in μΩ * cm and 13.3 μΩ * cm the resistivity of ISA® 13 in μΩ * cm, at +200 °C, respectively.

Result
An ISA® 13 wire with a diameter of 0.20 mm must be loaded with a current of 2 amps in order to increase its temperature by +200 °C.

Example 2

Problem
What is the temperature increase of ISA®-CHROM 60 wire with a diameter of 1.0 mm, if it is loaded with a current of 8 amps?

Solution

a) In accordance with the previously quoted formula, for +20 °C the conversion factor for ISA®-CHROM 60 alloy is calculated to be

Eq. 15: $$\sqrt{\frac{49\ \mu\Omega * \text{cm}}{111\ \mu\Omega * \text{cm}}} = 0.664$$

b) In order to get the load value for ISOTAN® wire with equal diameter, the value for ISA®-CHROM 60 must be divided by this value, thus

Eq. 16: $$I_{ISOTAN} = \frac{8\text{ A}}{0.664} = 12\text{ A}$$

This results in a value of 12 amps for ISOTAN® alloy.

If an ISOTAN® wire of equal diameter is loaded with the calculated 12 amps, its temperature will increase by somewhat less than +400 °C. As can be seen from the table 2, an overtemperature of +400 °C is achieved by applying a current of 12.3 amps.

The conversion factor determined as per a) applies to +20 °C; it must now be re-determined for +400 °C. It is 0.644, resulting from

Eq. 17: $$\sqrt{\frac{49\ \mu\Omega * \text{cm}}{118\ \mu\Omega * \text{cm}}} = 0.644$$

where 49 μΩ * cm is the resistivity of ISOTAN® in μΩ * cm and 118 μΩ * cm that of ISA®-CHROM 60 in μΩ * cm, at +400 °C, respectively.

Now if the load current of 8 amps for ISA®-CHROM 60 at +400 °C is re-calculated for ISOTAN®, a value of 12.4 amps for ISOTAN® wire with equal diameter will result. Since for +400 °C a value of 12.3 amps applies, you will get the following:

Result
If an ISA®-CHROM 60 wire with a diameter of 1.0 mm is loaded with a current of 8 amps, its temperature will increase by somewhat more than +400 °C.

Current-Carrying Capacity of Flat Wires
For round wires the diameter is sufficient to determine the data previously quoted. For ribbons the thickness and above all, the width must be taken into consideration. When making comparisons, the table containing the cross-sectional values of standard ribbons with rounded-off edges vs. those of round wires should be consulted.

At high temperature (+600 °C) or if for other reasons the proportion of heat dissipation by radiation exceeds the dissipation by convection, flat wires and ribbons of any dimension have a current-carrying capacity greater than that of round wires with an equal cross-sectional area, due to their larger surface area.

In case of the heat dissipation taking place mainly by convection – generally at low temperatures -, the current carrying capacity of flat wires and ribbons will exceed that of flat wires of an equal cross-sectional area only for ratios between width and thickness of more than 15 : 1.

If flat wires are wound around a carrier there will be a larger contact area available for heat transfer to the carrier by heat conductance as compared with round wires, but no generally valid data can be given as to a possibly higher current-carrying capacity. For heat dissipation to the outside, of course, only a part, i. e. one half of the surface of the ribbon is available; this must be kept in mind when making calculations. The following tables give information on the resistance, surface and weight of flat ISOTAN® wires, referenced at 1 m. In addition they contain data as to the load currents for ribbons of ISOTAN® at overtemperatures of +100/+200/+300 and +400 °C.

The following should be mentioned

Since the edges are rounded-off, the cross-sectional area and resistance of flat wires are calculated by the formula below.

The factor 0.215 refers to the optimal cross section with an edge rounding being equal to an optimal semicircle. As this is not a matter of fact, the real geometry may deviate from the calculated value.

Calculation of the Cross-Sectional Area and Resistance of Flat Wires

Eq. 18: $$R = \frac{\rho_{el} * l * 10^{-3}}{a * (b - a * 0.215)}$$

Eq. 19: $$A = a\,(b - a * 0.215)$$

Eq. 20: $$O = [a\,(\pi - 2) + 2b] * l$$

a = Thickness in mm
b = Width in mm
l = Length in mm
R = Resistance in Ω
A = Cross-sectional area in mm²
O = Surface in mm²
ρ_{el} = Resistivity in Ω * mm * m^{-1}

The values in the current-carrying capacity tables refer to bare wired or bare ribbon. Oxidized wire and ribbon can, due to improved heat dissipation, withstand a load increase of up to 20 %, expressed in Watt per cm².

The current-carrying capacity of ribbons of other alloys can be calculated with the same method as described for wires.

Table 3 // **Diameter of Round Wires of Equal Cross-Sectional Area in mm**

thickness	**width/b in mm**									
a in mm	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
0.05	0.25	0.36	0.44	0.50	0.56	0.62	0.67	0.71	0.76	0.80
0.06	0.27	0.39	0.48	0.55	0.62	0.68	0.73	0.78	0.83	0.87
0.07	0.30	0.42	0.52	0.60	0.67	0.73	0.79	0.84	0.89	0.94
0.08	0.32	0.45	0.55	0.64	0.71	0.78	0.84	0.90	0.96	1.01
0.09	0.34	0.48	0.58	0.68	0.76	0.83	0.89	0.96	1.01	1.07
0.10	0.35	0.50	0.62	0.71	0.80	0.87	0.94	1.01	1.07	1.13
0.12	0.39	0.55	0.67	0.78	0.87	0.96	1.03	1.10	1.17	1.23
0.14	0.42	0.59	0.73	0.84	0.94	1.03	1.11	1.19	1.26	1.33
0.16	0.44	0.63	0.78	0.90	1.01	1.10	1.19	1.27	1.35	1.42
0.18	0.47	0.67	0.82	0.95	1.07	1.17	1.26	1.35	1.43	1.51
0.20	0.49	0.71	0.87	1.00	1.12	1.23	1.33	1.42	1.51	1.59
0.22	0.52	0.74	0.91	1.05	1.18	1.29	1.40	1.49	1.58	1.67
0.24	0.54	0.77	0.95	1.10	1.23	1.35	1.46	1.56	1.65	1.74
0.26	0.56	0.80	0.99	1.14	1.28	1.40	1.52	1.62	1.72	1.81
0.28	0.58	0.83	1.02	1.19	1.33	1.46	1.57	1.68	1.79	1.88
0.30	0.60	0.86	1.06	1.23	1.37	1.51	1.63	1.74	1.85	1.95
0.35	0.65	0.93	1.14	1.32	1.48	1.62	1.76	1.88	1.99	2.10
0.40	0.68	0.99	1.22	1.41	1.58	1.74	1.88	2.01	2.13	2.25
0.45	0.72	1.04	1.29	1.50	1.68	1.84	1.99	2.13	2.26	2.38
0.50	0.75	1.10	1.36	1.57	1.76	1.94	2.09	2.24	2.38	2.51
0.60		1.20	1.48	1.72	1.93	2.12	2.29	2.45	2.60	2.75
0.70		1.28	1.59	1.85	2.08	2.28	2.47	2.64	2.81	2.96
0.80		1.36	1.70	1.97	2.22	2.44	2.64	2.82	3.00	3.16
0.90		1.44	1.79	2.09	2.35	2.58	2.79	2.99	3.18	3.35
1.00		1.51	1.88	2.20	2.47	2.71	2.94	3.15	3.34	3.53
1.20			2.05	2.39	2.69	2.96	3.21	3.44	3.65	3.86
1.40			2.19	2.57	2.89	3.19	3.46	3.70	3.94	4.16
1.60			2.33	2.73	3.08	3.39	3.68	3.95	4.20	4.44
1.80			2.45	2.88	3.25	3.59	3.89	4.18	4.44	4.69
2.00			2.56	3.02	3.41	3.77	4.09	4.39	4.67	4.94

Table 4 // **Flat Wires of ISOTAN® – Grams per Meter (g * m^{-1})**

thick-ness a in mm	width/b in mm 1	2	3	4	5	6	7	8	9	10
0.05	0.44	0.89	1.3	1.8	2.2	2.7	3.1	3.6	4.0	4.4
0.06	0.53	1.1	1.6	2.1	2.7	3.2	3.7	4.3	4.8	5.3
0.07	0.61	1.2	1.9	2.5	3.1	3.7	4.4	5.0	5.6	6.2
0.08	0.70	1.4	2.1	2.8	3.5	4.3	5.0	5.7	6.4	7.1
0.09	0.79	1.6	2.4	3.2	4.0	4.8	5.6	6.4	7.2	8.0
0.10	0.87	1.8	2.7	3.5	4.4	5.3	6.2	7.1	8.0	8.9
0.12	1.0	2.1	3.2	4.2	5.3	6.4	7.4	8.5	9.6	10.7
0.14	1.2	2.5	3.7	4.9	6.2	7.4	8.7	9.9	11.2	12.4
0.16	1.4	2.8	4.2	5.6	7.1	8.5	9.9	11.3	12.8	14.2
0.18	1.5	3.1	4.7	6.3	7.9	9.6	11.2	12.8	14.4	16.0
0.20	1.7	3.5	5.3	7.0	8.8	10.6	12.4	14.2	15.9	17.7
0.22	1.9	3.8	5.8	7.7	9.7	11.7	13.6	15.6	17.5	19.5
0.24	2.0	4.2	6.3	8.4	10.6	12.7	14.8	17.0	19.1	21.2
0.26	2.2	4.5	6.8	9.1	11.4	13.8	16.1	18.4	20.7	23.0
0.28	2.3	4.8	7.3	9.8	12.3	14.8	17.3	19.8	22.3	24.8
0.30	2.5	5.2	7.8	10.5	13.2	15.8	18.5	21.2	23.9	26.5
0.35	2.9	6.0	9.1	12.2	15.3	18.5	21.6	24.7	27.8	30.9
0.40	3.3	6.8	10.4	13.9	17.5	21.1	24.6	28.2	31.7	35.3
0.45	3.6	7.6	11.6	15.6	19.6	23.6	27.6	31.7	35.7	39.7
0.50	4.0	8.4	12.9	17.3	21.8	26.2	30.7	35.1	39.6	44.0
0.60		10.0	15.3	20.7	26.0	31.4	36.7	42.0	47.4	52.7
0.70		11.5	17.8	24.0	30.2	36.4	42.7	48.9	55.1	61.4
0.80		13.0	20.1	27.3	34.4	41.5	48.6	55.7	62.9	70.0
0.90		14.5	22.5	30.5	38.5	46.5	54.5	62.5	70.5	78.6
1.00		15.9	24.8	33.7	42.6	51.5	60.4	69.3	78.2	87.1
1.20			29.3	40.0	50.6	61.3	72.0	82.7	93.4	104
1.40			33.6	46.1	58.5	71.0	83.5	95.9	108	121
1.60			37.8	52.1	66.3	80.5	94.8	109	123	138
1.80			41.9	57.9	73.9	89.9	106	122	138	154
2.00			45.7	63.5	81.3	99.1	117	135	153	170

Table 5 // **Surface of Flat Wires in cm² * m^{-1}**

thick-ness a in mm	width/b in mm 1	2	3	4	5	6	7	8	9	10
0.05	20.6	40.6	60.6	80.6	101	121	141	161	181	201
0.06	20.7	40.7	60.7	80.7	101	121	141	161	181	201
0.07	20.8	40.8	60.8	80.8	101	121	141	161	181	201
0.08	20.9	40.9	60.9	80.9	101	121	141	161	181	201
0.09	21.0	41.0	61.0	81.0	101	121	141	161	181	201
0.10	21.1	41.1	61.1	81.1	101	121	141	161	181	201
0.12	21.4	41.4	61.4	81.4	101	121	141	161	181	201
0.14	21.6	41.6	61.6	81.6	102	122	142	162	182	202
0.16	21.8	41.8	61.8	81.8	102	122	142	162	182	202
0.18	22.1	42.1	62.1	82.1	102	122	142	162	182	202
0.20	22.3	42.3	62.3	82.3	102	122	142	162	182	202
0.22	22.5	42.5	62.5	82.5	103	123	143	163	183	203
0.24	22.7	42.7	62.7	82.7	103	123	143	163	183	203
0.26	23.0	43.0	63.0	83.0	103	123	143	163	183	203
0.28	23.2	43.2	63.2	83.2	103	123	143	163	183	203
0.30	23.4	43.4	63.4	83.4	103	123	143	163	183	203
0.35	24.0	44.0	64.0	84.0	104	124	144	164	184	204
0.40	24.6	44.6	64.6	84.6	105	125	145	165	185	205
0.45	25.1	45.1	65.1	85.1	105	125	145	165	185	205
0.50	25.7	45.7	65.7	85.7	106	126	146	166	186	206
0.60		46.8	66.8	86.8	107	127	147	167	187	207
0.70		48.0	68.0	88.0	108	128	148	168	188	208
0.80		49.1	69.1	89.1	109	129	149	169	189	209
0.90		50.3	70.3	90.3	110	130	150	170	190	210
1.00		51.4	71.4	91.4	111	131	151	171	191	211
1.20			73.7	93.7	114	134	154	174	194	214
1.40			76.0	96.0	116	136	156	176	196	216
1.60			78.3	98.3	118	138	158	178	198	218
1.80			80.5	101	121	141	161	181	201	221
2.00			82.8	103	123	143	163	183	203	223

Table 6 // **Current-Carrying Capacity of Flat Wires of ISOTAN® in Amps for an Overtemperature of +100 °C,** Horizontally stretched in still air of +20 °C

thick-ness a in mm	width/b in mm									
	1	2	3	4	5	6	7	8	9	10
0.05	0.93	1.60	2.13	2.66	3.20	3.64	4.12	4.56	5.03	5.51
0.06	1.02	1.75	2.33	2.91	3.50	3.98	4.50	4.99	5.51	6.03
0.07	1.10	1.89	2.52	3.15	3.78	4.31	4.87	5.40	5.96	6.52
0.08	1.17	2.02	2.69	3.36	4.04	4.60	5.20	5.77	6.36	6.96
0.09	1.25	2.14	2.85	3.56	4.28	4.88	5.51	6.11	6.74	7.38
0.10	1.31	2.25	3.00	3.75	4.51	5.14	5.80	6.43	7.10	7.77
0.12	1.44	2.45	3.29	4.11	4.94	5.63	6.35	7.04	7.78	8.51
0.14	1.55	2.67	3.55	4.44	5.34	6.08	6.87	7.61	8.41	9.20
0.16	1.66	2.85	3.80	4.75	5.71	6.50	7.35	8.14	9.00	9.84
0.18	1.76	3.02	4.03	5.04	6.05	6.89	7.79	8.63	9.53	10.4
0.20	1.85	3.19	4.25	5.31	6.38	7.27	8.22	9.10	10.0	11.0
0.22	1.95	3.34	4.46	5.57	6.70	7.63	8.62	9.55	10.5	11.5
0.24	2.03	3.49	4.66	5.82	7.00	7.97	9.00	10.0	11.0	12.0
0.26	2.12	3.64	4.84	6.06	7.28	8.29	9.37	10.4	11.5	12.5
0.28	2.20	3.77	5.03	6.28	7.55	8.60	9.72	10.8	11.9	13.0
0.30	2.27	3.91	5.21	6.51	7.82	8.91	10.1	11.2	12.3	13.5
0.35	2.46	4.22	5.62	7.03	8.45	9.63	10.9	12.1	13.3	14.6
0.40	2.62	4.51	6.00	7.51	9.02	10.3	11.6	12.9	14.2	15.5
0.45	2.78	4.78	6.37	7.97	9.58	10.9	12.3	13.7	15.1	16.5
0.50	2.93	5.04	6.72	8.40	10.1	11.5	13.0	14.4	15.9	17.4
0.60		5.52	7.36	9.21	11.1	12.6	14.2	15.8	17.4	19.1
0.70		5.97	7.95	9.94	12.0	13.6	15.4	17.0	18.8	20.6
0.80		6.37	8.49	10.6	12.8	14.5	16.4	18.2	20.1	22.0
0.90		6.77	9.02	11.3	13.6	15.4	17.4	19.3	21.3	23.3
1.00		7.13	9.50	11.9	14.3	16.3	18.4	20.4	22.5	24.6
1.20			10.4	12.9	15.6	17.7	20.0	22.2	24.5	26.8
1.40			11.2	14.0	16.9	19.2	21.7	24.0	26.5	29.0
1.60			12.0	15.0	18.0	20.5	23.2	25.7	28.3	31.0
1.80			12.8	15.9	19.1	21.8	24.6	27.3	30.1	33.0
2.00			13.5	16.8	20.1	22.9	25.9	28.7	31.7	34.7

Table 7 // **Current-Carrying Capacity of Flat Wires of ISOTAN® in Amps for an Overtemperature of +200 °C,** Horizontally stretched in still air of +20 °C

thick-ness a in mm	width/b in mm									
	1	2	3	4	5	6	7	8	9	10
0.05	1.40	2.26	3.11	3.94	4.75	5.53	6.29	7.06	7.86	8.60
0.06	1.53	2.47	3.41	4.31	5.19	6.05	6.88	7.72	8.60	9.38
0.07	1.66	2.68	3.68	4.66	5.62	6.55	7.45	8.35	9.30	10.1
0.08	1.77	2.86	3.93	4.98	6.00	7.00	7.95	8.91	9.93	10.8
0.09	1.88	3.03	4.17	5.28	6.36	7.41	8.43	9.45	10.5	11.5
0.10	1.98	3.19	4.39	5.56	6.70	7.81	8.88	9.95	11.1	12.1
0.12	2.17	3.49	4.81	6.09	7.34	8.55	9.72	10.9	12.1	13.3
0.14	2.34	3.78	5.20	6.58	7.93	9.24	10.5	11.8	13.1	14.3
0.16	2.50	4.04	5.56	7.04	8.48	9.88	11.2	12.6	14.0	15.3
0.18	2.65	4.28	5.89	7.46	8.99	10.5	11.9	13.4	14.9	16.2
0.20	2.80	4.51	6.21	7.87	9.48	11.0	12.6	14.1	15.7	17.1
0.22	2.94	4.74	6.52	8.25	9.94	11.6	13.2	14.8	16.5	18.0
0.24	3.07	4.95	6.81	8.62	10.40	12.1	13.8	15.4	17.2	18.8
0.26	3.19	5.15	7.09	8.98	10.8	12.6	14.3	16.1	17.9	19.5
0.28	3.31	5.34	7.35	9.31	11.2	13.1	14.9	16.7	18.6	20.3
0.30	3.43	5.53	7.62	9.64	11.6	13.5	15.4	17.3	19.2	21.0
0.35	3.71	5.98	8.23	10.4	12.6	14.6	16.6	18.6	20.7	22.7
0.40	3.96	6.38	8.78	11.1	13.4	15.6	17.8	19.9	22.2	24.2
0.45	4.20	6.78	9.33	11.8	14.2	16.6	18.9	21.1	23.6	25.7
0.50	4.43	7.17	9.85	12.4	15.0	17.5	19.9	22.3	24.8	27.1
0.60		7.75	10.8	13.6	16.4	19.1	21.8	24.4	27.2	29.7
0.70		8.45	11.6	14.7	17.7	20.8	23.5	26.4	29.4	32.1
0.80		9.03	12.4	15.7	19.0	22.1	25.1	28.2	31.4	34.2
0.90		9.58	13.2	16.7	20.1	23.4	26.7	29.9	33.3	36.3
1.00		10.10	13.9	17.6	21.2	24.7	28.1	31.5	35.1	38.3
1.20			15.2	19.2	23.1	26.9	30.6	34.3	38.3	41.7
1.40			16.4	20.8	25.0	29.1	33.2	37.2	41.4	45.2
1.60			17.5	22.2	26.7	31.1	35.4	39.7	44.2	48.3
1.80			18.6	23.6	28.4	33.1	37.7	42.2	47.0	51.3
2.00			19.6	24.8	29.9	34.8	39.6	44.4	49.5	54.0

Table 8 // **Current-Carrying Capacity of Flat Wires of ISOTAN® in Amps for an Overtemperature of +300 °C,** Horizontally stretched in still air of +20 °C

thick-ness a in mm	width/b in mm									
	1	2	3	4	5	6	7	8	9	10
0.05	1.94	3.09	4.19	5.33	6.43	7.55	8.62	9.70	10.7	11.8
0.06	2.12	3.38	4.58	5.83	7.03	8.26	9.43	10.6	11.7	12.9
0.07	2.29	3.66	4.96	6.31	7.61	8.93	10.2	11.5	12.7	13.9
0.08	2.45	3.91	5.29	6.73	8.12	9.54	10.9	12.3	13.5	14.9
0.09	2.59	4.14	5.61	7.14	8.61	10.1	11.6	13.0	14.3	15.8
0.10	2.73	4.36	5.91	7.52	9.07	10.6	12.2	13.7	15.1	16.6
0.12	2.99	4.77	6.47	8.24	9.93	11.7	13.3	15.0	16.5	18.1
0.14	3.23	5.16	7.00	8.90	10.7	12.6	14.4	16.2	17.9	19.6
0.16	3.46	5.52	7.48	9.52	11.5	13.5	15.4	17.3	19.1	21.0
0.18	3.66	5.85	7.93	10.1	12.2	14.3	16.3	18.4	20.3	22.3
0.20	3.86	6.17	8.36	10.6	12.8	15.1	17.2	19.4	21.4	23.5
0.22	4.05	6.47	8.77	11.2	13.5	15.8	18.1	20.3	22.4	24.6
0.24	4.23	6.76	9.16	11.7	14.1	16.5	18.9	21.2	23.4	25.7
0.26	4.41	7.04	9.54	12.1	14.6	17.2	19.6	22.1	24.4	26.8
0.28	4.57	7.30	9.89	12.6	15.2	17.8	20.4	22.9	25.3	27.8
0.30	4.73	7.56	10.2	13.0	15.7	18.5	21.1	23.7	26.2	28.8
0.35	5.11	8.17	11.1	14.1	17.0	20.0	22.8	25.6	28.3	31.3
0.40	5.46	8.72	11.8	15.0	18.1	21.3	24.3	27.4	30.2	33.2
0.45	5.80	9.26	12.5	15.9	19.3	22.6	25.8	29.1	32.1	35.2
0.50	6.11	9.72	13.2	16.8	20.3	23.8	27.2	30.6	33.8	37.1
0.60		10.7	14.5	18.4	22.2	26.1	29.8	33.6	37.2	40.7
0.70		11.6	15.7	19.9	24.0	28.2	32.2	36.2	40.0	43.9
0.80		12.3	16.7	21.3	25.7	30.1	34.4	38.7	42.7	46.9
0.90		13.1	17.7	22.6	27.2	32.0	36.5	41.1	45.4	49.8
1.00		13.8	18.7	23.8	28.7	33.7	38.5	43.3	47.8	52.5
1.20			20.4	25.9	31.3	36.7	42.0	47.2	52.1	57.2
1.40			22.1	28.1	33.9	39.8	45.5	51.1	56.4	61.9
1.60			23.6	30.0	36.2	42.5	48.5	54.6	60.2	66.1
1.80			25.1	31.9	38.5	45.2	51.6	58.0	64.1	70.3
2.00			26.4	33.6	40.5	47.5	54.3	61.1	67.4	74.0

Table 9 // **Current-Carrying Capacity of Flat Wires of ISOTAN® in Amps for an Overtemperature of +400 °C,** Horizontally stretched in still air of +20 °C

thick-ness a in mm	width/b in mm									
	1	2	3	4	5	6	7	8	9	10
0.05	2.44	3.88	5.3	6.7	8.1	9.5	10.9	12.3	13.6	15.0
0.06	2.67	4.2	5.8	7.3	8.8	10.4	11.9	13.4	14.9	16.4
0.07	2.89	4.6	6.3	7.9	9.6	11.2	12.9	14.5	16.1	17.7
0.08	3.08	4.9	6.7	8.4	10.2	12.0	13.8	15.5	17.2	18.9
0.09	3.27	5.2	7.1	8.9	10.8	12.7	14.6	16.4	18.2	20.0
0.10	3.44	5.5	7.5	9.4	11.4	13.4	15.4	17.3	19.2	21.1
0.12	3.8	6.0	8.2	10.3	12.5	14.7	16.8	18.9	21.0	23.1
0.14	4.1	6.5	8.8	11.1	13.5	15.9	18.2	20.5	22.7	25.0
0.16	4.4	6.9	9.5	11.9	14.4	17.0	19.4	21.9	24.3	26.7
0.18	4.6	7.3	10.0	12.6	15.3	18.0	20.6	23.3	25.8	28.3
0.20	4.9	7.7	10.5	13.3	16.1	19.0	21.7	24.5	27.2	29.9
0.22	5.1	8.1	11.1	14.0	16.9	19.9	22.8	25.7	28.5	31.3
0.24	5.3	8.5	11.6	14.6	17.7	20.8	23.8	26.8	29.8	32.7
0.26	5.6	8.8	12.0	15.2	18.4	21.6	24.8	27.9	31.0	34.1
0.28	5.8	9.2	12.5	15.8	19.1	22.4	25.7	28.9	32.2	35.4
0.30	6.0	9.5	12.9	16.3	19.8	23.2	26.6	30.0	33.3	36.6
0.35	6.5	10.2	14.0	17.6	21.4	25.1	28.8	32.4	36.0	39.5
0.40	6.9	10.9	14.9	18.8	22.8	26.8	30.7	34.6	38.4	42.2
0.45	7.3	11.6	15.8	20.0	24.2	28.5	32.6	36.7	40.8	44.8
0.50	7.7	12.2	16.7	21.1	25.5	30.0	34.4	38.7	43.0	47.2
0.60		13.4	18.3	23.1	28.0	32.9	37.7	42.4	47.1	51.8
0.70		14.5	19.6	24.9	30.2	35.5	40.7	45.8	50.9	55.9
0.80		15.5	21.1	26.6	32.3	37.9	43.4	48.9	54.4	59.7
0.90		16.4	22.4	28.3	34.3	40.2	46.1	51.9	57.7	63.4
1.00		17.3	23.6	29.8	36.1	42.4	48.6	54.7	60.8	66.8
1.20			25.7	32.5	39.3	46.2	53.0	59.6	66.3	72.8
1.40			27.8	35.2	42.6	50.0	57.3	64.5	71.7	78.8
1.60			29.7	37.5	45.5	53.4	61.2	68.9	76.6	84.2
1.80			31.6	40.0	48.4	56.8	65.1	73.3	81.5	89.5
2.00			33.3	42.0	50.9	59.8	68.5	77.1	85.7	94.2

Available Types

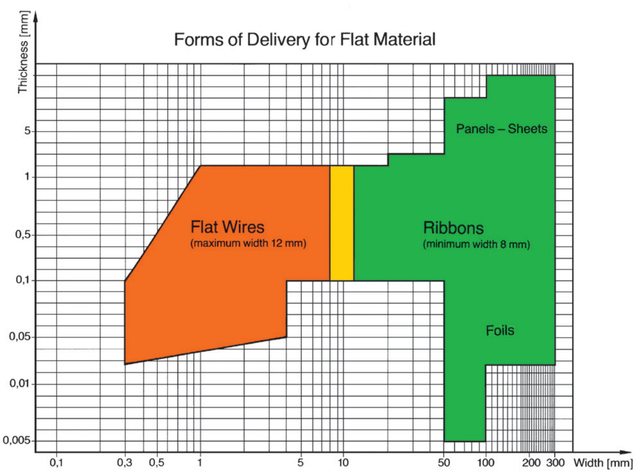
Our alloys are available in the form of
- Annealed bare wires; on request ISOTAN®, ISA®-CHROM 60 and ISA®-CHROM 80 can be manufactured with an insulating oxide film
- ML-enamel
- Solderable enamel (polyurethane), heat resistant up to +150 °C
- Heat resistant enamel (polyimide), not solder able, up to +200 °C
- Enamelled wires with or without synthetic (rayon) or silk or glass fibre cover
- Annealed flat wires with rounded-off edges (calculation of cross-sectional area see part C)
- Annealed ribbons, also in sheet or panel form
- Foils
- Strands up to a cross-sectional area of 4.0 mm² with up to 48 single wires.
- Rods, drawn and straightened, also forged rods

On request our alloys can also be delivered with special values of hardness resp. tensile strength.

Dimensional Range

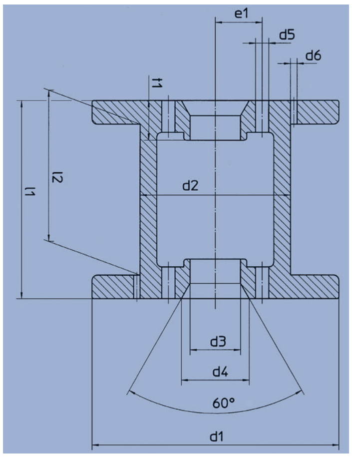
Bare wires	0.01–10 mm Ø
Insulated wires	0.01–2 mm Ø
Flat wires thickness	0.05–2 mm Ø
Metal sheets and panels thickness	0.10–10 mm Ø
Foils thickness	0.005–0.10 mm Ø

The dimensional ranges are illustrated in the following diagram; details are given on request.



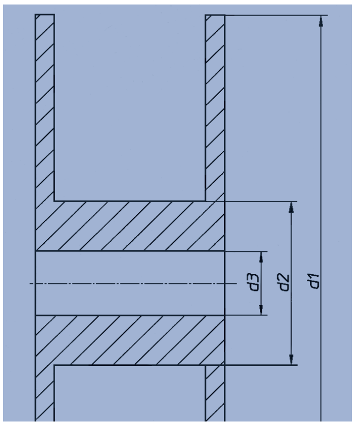
Packing

Wires of less than 1 mm diameter and **flat wires of less than 0.80 mm** thickness and a **maximum width of 5 mm** are delivered on plastic spools according to DIN IEC 264 resp. on American standard spools in accordance with the tables on the right.



Insulated wires are delivered on plastic spools as for bare wires. **Stranded wires** are delivered on special spools holding up to 100 kg per spool in one length. **Ribbon** with a maximum width of 10 mm can be delivered on special spools; ribbon of more than 10 mm width is delivered spirally wound in the form of disks with an inner diameter of 100 mm and an outer diameter of 300 mm maximum. **Wires** with a diameter of more than 1 mm can be delivered on spools or wound in coils as per the table on the right.

Reels for tapes, tubes and cables



Spools according to DIN IEC264

Spool Dimensions (mm)					Weight of Wound-Up Wire	On Plastic Spools Round Wires up to 1.0 Diam. Flat Wires up to 5.0 mm Width and 0.8 mm Thickness			
Spool Diameter			Spool Width						
d_1	d_2	d_3	l_1	l_2	kg approx.	</= 0.10	> 0.10 </= 0.40	> 0.40 </= 0.70	> 0.70 </= 1.00
50	32	11	50	38	0.1	+			
63	40	11	63	49	0.4	+			
80	50	16	80	64	0.7	+	+		
100	63	16	100	80	1.5		+		
125	80	16	125	100	3.0		+	+	
160	100	22	160	128	7.0		+	+	+
200	125	22	200	160	13.0		+	+	+
250	160	22	200	160	23.0		+	+	+
355	224	36	200	160	45.0			+	+
500	315	36	250	180	80.0				+

American Spools

63	44.3	16	61	51	0.25	Designation 060 „half-cut“
63	44.3	16	86	76	0.45	Designation 065 „1 lb spool“

Special spool

for wires > 0.8 mm diam. with reference to DIN IEC 264

560	315	127	400	300	200	> 0.8 mm

Special spool with conical flanges for finest sizes,
outer dimensions correspond to the American ,,half-cut"-spool.

Spool with conical flanges,
in accordance with DIN EN 60264-5-1; to be agreed upon.

Coils

Round Wires > 1mm diam.			Flat Wires > 5.0 mm Width > 0.8 mm Thickness
Wire Diameter resp. Width (mm)	Inner Diameter of Coil (mm) approx.	Outer Diameter of Coil (mm) approx.	Weight of Coil (kg) approx.
> 1-0 – 2-5	300	400	20
> 2-5 – 6-0	550	700	60

Materials

PS = High impact polystyrene
ABS = Acrylonitrile Butadiene Styrene
PE = Polyethylene
Other materials and further information on request.

Packaging

On request

Remarks

All measures, weights and loads indicated are approximate figures. Tolerances and deviations as usual in the trade.

Dimensions in mm, all dimensions are nominal dimensions

Illustration No. front page						Weight in g	Winding volume in cm^3	possible materials	remarks
Type	**d1**	**d2**	**d3**	**L1**	**L2**				
MP250	250	60	20	30	0-15	410	693	PS	L 2 variable by sliding flange

Technical Terms of Delivery

For bare wires the terms of delivery of DIN 46460, part 1, apply; dimensions and resistance values are standardized in DIN 46461 and 46463. In general for linear resistance a tolerance of ±5 % from the nominal value applies; this may increase to ±10 % maximum for thin wires and low resistance alloys. Within one wire length the tolerance is approx. ±1 % maximum from the actual resistance per meter. For oxidized wires the technical terms of delivery are summarized in DIN 46464.

Wires insulated by an oxide layer can be used at temperatures up to the maximum working temperature for bare wires. The break-down voltage is more than 10 V for ISOTAN® and more than 3 V for the nickel-chromium alloys ISA®-CHROM 80 and ISA®-CHROM 60. For enamelled and silk-covered wires the terms of delivery of DIN 46460, Parts 2 – 4, and DIN 46462 apply. Enamelled wires are treated with a so-called solderable enamel (DIN designation Type V); the wires may be directly tinned if the alloys permits. On request a hightemperature resistant enamel (DIN designation Type W 200), usable at temperatures of up to +200 °C, or even more for short periods, is available.

The break-down voltage for both types ranges from 700 to more than 2500 V, depending on the diameter. The wires can also be covered with rayon, natural silk or glass fibre. Subsequent impregnation with silicone varnish for improved adhesion is possible. The breakdown voltage is several hundred volts.

For certain applications, especially if insulated wires are used for heating bimetals, a combination of several insulation types is recommended. Flat wires of resistance alloys are standardized in DIN 46465. It should be noted that the nominal dimensions quoted there often will not meet the requirements of our customers and that for this reason we have chosen a different gradation.

For resistance alloys supplied as ribbon or sheet, no special standard exists. Here we apply the permissible values stated in DIN 1791 for copper and wrought copper alloys, as regards thickness and width tolerances.

For stranded wires of resistance alloys, too, no special standards exist. The technical terms of delivery must be negotiated individually. If stranded wires are used for heating cables, however, the regulations of VDE 0253 must be observed.

On request special tolerance values can be offered.

Table 10 // **Dimensions in mm**

Nominal Diameter d1	Increased Diameter d2 - d1		Outer Diameter d2			
	L	2L	min.	max.	min.	max.
0.020	0.005	0.009	0.023	0.029	0.027	0.036
0.025	0.006	0.010	0.029	0.036	0.033	0.042
0.030	0.006	0.011	0.034	0.042	0.039	0.048
0.040	0.007	0.012	0.045	0.053	0.050	0.060
0.045	0.008	0.013	0.051	0.059	0.056	0.066
0.050	0.008	0.014	0.056	0.064	0.062	0.072
0.060	0.009	0.016	0.067	0.076	0.074	0.084
0.071	0.010	0.017	0.079	0.089	0.086	0.097
0.080	0.011	0.018	0.088	0.099	0.095	0.108
0.090	0.012	0.019	0.098	0.111	0.106	0.120
0.100	0.012	0.021	0.109	0.122	0.117	0.123
0.125	0.014	0.023	0.136	0.150	0.145	0.161
0.140	0.015	0.024	0.151	0.166	0.160	0.179
0.150	0.016	0.025	0.162	0.177	0.171	0.191
0.160	0.017	0.026	0.173	0.188	0.182	0.202
0.180	0.018	0.028	0.193	0.210	0.203	0.225
0.200	0.019	0.030	0.214	0.231	0.225	0.248
0.250	0.022	0.034	0.266	0.285	0.278	0.304
0.280	0.024	0.036	0.297	0.318	0.309	0.338
0.300	0.025	0.037	0.318	0.339	0.330	0.360
0.400	0.028	0.043	0.418	0.445	0.433	0.468
0.450	0.030	0.046	0.469	0.498	0.485	0.524
0.500	0.031	0.049	0.519	0.551	0.537	0.578
0.600	0.035	0.054	0.620	0.657	0.639	0.686
0.800	0.041	0.062	0.821	0.869	0.842	0.902
0.900	0.043	0.066	0.921	0.973	0.944	1.010
1.000	0.046	0.070	1.021	1.079	1.045	1.117
1.250	0.053	0.080	1.271	1.343	1.298	1.387
1.400	0.056	0.085	1.421	1.499	1.450	1.548
1.500	0.059	0.090	1.521	1.605	1.552	1.654

E // CORROSION RESISTANCE

At room temperature the alloys manufactured by us exhibit good corrosion resistance in the bare condition. In order to avoid corrosion during storage, it is recommended that the environment should be as dry as possible.

Alloys with a high copper content have a tendency to surface corrosion after long periods of storage.

It should be kept in mind that oxidized wires of nickel-chromium alloys can be destroyed when stored in a moist environment. The alloy MANGANIN® is susceptible to stress crack corrosion; it also requires to be stored at a dry place.

The corrosion resistance characteristics at maximum working temperature can be seen from the table below.

On completion of soldering, brazing or welding work the flux must be removed very thoroughly, since it can contribute to corrosion, especially at higher temperatures.

<table>
<tr><th rowspan="3">Designation</th><th colspan="6">Corrosion Resistant up to Maximum Working Temperature against</th></tr>
<tr><th rowspan="2">Atmospheric Corrosion at +20 °C</th><th rowspan="2">Air and Other Oxygen Containing Gases</th><th rowspan="2">Nitrogen Containing Gases with Little Oxygen Content</th><th colspan="2">Sulphur-Containing Gases</th><th rowspan="2">Carburization</th></tr>
<tr><th>Oxidyzing</th><th>Reductive</th></tr>
<tr><td>ISAOHM®</td><td rowspan="17">high</td><td rowspan="6">high</td><td rowspan="6">high</td><td>high</td><td>high</td><td rowspan="19">high</td></tr>
<tr><td>ISA®-CHROM 60</td><td rowspan="3">medium</td><td rowspan="3">medium</td></tr>
<tr><td>ISA®-CHROM 80</td></tr>
<tr><td>ISA®-CHROM 30</td></tr>
<tr><td>ISOTAN®</td><td rowspan="2">high</td><td rowspan="11">low</td></tr>
<tr><td>ISA®-NICKEL</td></tr>
<tr><td>MANGANIN®</td><td>medium</td><td>medium</td><td>medium</td></tr>
<tr><td>NICKELIN W</td><td rowspan="2">high</td><td rowspan="2">high</td><td>high</td></tr>
<tr><td>RESISTHERM</td><td rowspan="5">medium</td></tr>
<tr><td>ISA-ZIN</td><td rowspan="4">medium</td><td rowspan="4">medium</td></tr>
<tr><td>ZERANIN® 30</td></tr>
<tr><td>ALLOY 127</td></tr>
<tr><td>ALLOY 90</td></tr>
<tr><td>ISA® 13</td><td rowspan="2">low</td><td rowspan="2">low</td><td rowspan="6">low</td></tr>
<tr><td>ALLOY 60</td></tr>
<tr><td>NICKEL</td><td>high</td><td>high</td><td>high</td></tr>
<tr><td>ALLOY 30</td><td rowspan="3">low</td><td rowspan="3">low</td><td rowspan="3">low</td></tr>
<tr><td>CuNi1</td><td rowspan="2">medium</td></tr>
<tr><td>E-COPPER</td></tr>
</table>

F // INSTRUCTIONS FOR TREATMENT

The alloys delivered by Isabellenhütte have good working characteristics.

The following instructions should be observed:

Winding
All wires should be treated as carefully as possible, with a tension below the yield point. The yield point can be taken as being approx. 50 % below tensile strength in annealed condition.

Aging
Even when winding a resistance wire with little tension deformation can take place. By simple bending, mechanical stresses are built up in the wire. They affect the electrical resistance and should be minimized by heat treatment.

Copper alloys can increase their resistivity by deformation; for ISOTAN®, e. g. this increase can achieve up to 7 %. As regards nickel-chromium alloys, deformation reduces the resistivity, for ISAOHM® e. g. up to 10 %.

Heat treatment – which is also called artificial aging – is especially required when precision resistors are manufactured. Aging is a stabilization process; it can be accelerated considerably by applying temperatures well above ambient temperatures. The size of the aging temperature is determined by the material and especially by the insulation used.

In some cases artificial aging by temperature cycling is an advantage. Here temperature cycles between +20 °C and maximum aging temperature are repeatedly run. The aging temperature should not exceed +140 °C because of the sensitivity to heat of the wire insulation. Bare wires slightly begin to oxidize above +100 °C; this oxide layer can be removed by pickling.

Pickling
The type of pickling bath is mainly determined by the nature of the alloy. For MANGANIN® e. g. sulphuric chromic acid, for ZERANIN® nitric acid, for ISOTAN® also nitric acid or persulphate pickle is used; for nickel-chromium alloys pickling in phosphoric acid has proven its value. The immersion period lasts for 1 to 10 minutes depending on the alloy.

Soldering, Brazing and Welding of Resistance Alloys

Soldering
The copper alloys manufactured by Isabellenhütte can be soldered like pure copper, using normal solders and fluxes. Light abrasion of the areas to be soldered is recommended.

When soldering precision resistors a leadfree solder (e. g. L-SnAg5 according to DIN 1707) and only acid-free fluxes (preferably pure colophony) should be used. Even the smallest residual of aggressive fluxes causes corrosion of the wire thus alternation to the resistance. Solders containing lead may be subject to metallic alterations. The melting point of the solder must be such as to prevent softening over time. In general, however, brazing should be preferred.

When soldering precision resistors spot-soldering is recommended. The very high temperature coefficient of the electric resistance of tin (pure tin = 4600 ppm/K) affects also the temperature coefficient of the resistance material.

ISAOHM® alloy can only be soldered by using particularly aggressive fluxes, as used for soldering stainless steels (e. g. Soldaflux Z by BrazeTec). In addition, the surfaces must be roughened beforehand. But even then the bond does not have the quality as with copper alloys. In all cases the flux must be carefully removed.

Brazing
The soundest and most reliable bonds are made by brazing. Since the temperature coefficient and resistivity of the alloys for precision resistors are affected by heating, it is recommended to use low melting point brazing solders (L-Ag40Cd DIN 1707, e. g. "BrazeTec 5600") and to keep the brazing time as short as possible. Flux BrazeTec h has proved useful.

Welding
The alloys can be welded especially spot and butt welded. It must be kept in mind, however, that the electrical and heat conductivities as well as the melting points often greatly differ from the respective values of other materials.

Cutting
While with copper-nickel alloys no problems arise, nickel-chromium alloys and PURE NICKEL are tough and show high strength at high temperatures; they thus tend to "weld together" with the tools. This must be taken into consideration when drilling, threading or sawing. Under certain circumstances it may be more favourable to use hard, i. e. un-annealed, alloys.

Resistivity

	Ω/sq mil ft	Ω/CMF	μΩ/cub	Ω * mm²/m	μΩ * cm
Ω/sq mil ft	1	1.273	0.08333	0,0021167	0.21167
Ω/cir mil ft	0.7854	1	0.0654	0,0016624	0.16624
μΩ/cub	12	15.279	1	0,0254	2.54
Ω * mm²/m	472.44	601.54	39.37	1	100
μΩ * cm	4.7244	6.0154	0.3937	0,01	1

Ω - CMF: CMF = circular mil foot

The length of the wire is measured in feet.

The area is measured in circular mil and a mil is one thousandth of an inch.

A circular mil is the area of a circle with a diameter. of 1 mil.

$1\ \Omega - CMF = 0.1662 * 10^{-8}\ \Omega * m$

$1\ \Omega - CMF = 0,1662 * 10^{-6}\ \Omega * cm$

$1\ \Omega - CMF = 0.1662\ m\Omega * cm$

Electrical Resistance

	Ω / ft	Ω / yard	Ω / m
Ω / ft	1	3	3.281
Ω / yard	0.3333	1	1.094
Ω / m	0.3048	0.9144	1

Units of Length

	inch	foot	yard	mm	m
inch	1	0.0833	0.0278	25.4	0.0254
foot	12	1	0.3333	304.8	0.3048
yard	36	3	1	914.4	0.9144
mm	0.0394	0.0033	-	1	0.001
m	39.37	3,281	1,094	1,000	1

Unit of Surface Area

	squre inch	square foot	square yard	mm²	m²
1 square inch	1	-	-	645.2	-
1 square foot	144	1	0.1111	92,900	0.0929
1 square yard	1,296	9	1	-	0.8361
1 mm²	0.0016	-	-	1	10^{-6}
1 m²	1,550	10.76	1.196	10^{6}	1

Units of Space

	cubic inch	cubic foot	cubic yard	cm³	dm³
1 cubic inch	1	-	-	16,39	0.0164
1 cubic foot	1,728	1	0.037	-	28.32
1 cubic yard	46,656	27	1	-	764.6
1 cm³	0.061	-	-	1	0.001
1 dm³	61.02	0.035	-	1,000	1

Units of Weight

	oz	lb	g	kg
ounce (oz) [1)]	1	0,0625	28.35	0.028
pound (lb)	16	1	453.6	0.4536
gram (g)	0.0353	-	1	0.001
kilogram (kg)	35.274	2.2046	1,000	1

1) 1 troy ounce corresponds to 31.1035 g.

Density

	lb/cub in	g/cm³
lb/cub in	1	27.68
g/cm³	0.03613	1

Strength

	psi	Kp/mm²	MPa
psi	1	0.0007021	0.0069
Kp/mm²	1,422.3	1	9.81
MPa	145	0.102	1

Conversion of Units of the Coefficient of Thermal Conductivity (λ)

Units of λ	$\frac{W}{m\,K}$	$\frac{W}{cm\,K}$	$\frac{kcal}{cm\,s\,grd}$	$\frac{J}{cm\,s\,K}$	$\frac{kpm}{cm\,s\,grd}$
$\frac{W}{m\,K}$	1	10^{-2}	$2.39 \cdot 10^{-6}$	10^{-2}	$1.02 \cdot 10^{-3}$
$\frac{W}{cm\,K}$	10^{2}	1	$2.39 \cdot 10^{-4}$	1	0.102
$\frac{kcal}{cm\,s\,grd}$	$0.419 \cdot 10^{6}$	$4.187 \cdot 10^{3}$	1	$4.187 \cdot 10^{3}$	$4.27 \cdot 10^{2}$
$\frac{J}{cm\,s\,K}$	100	1	$2.39 \cdot 10^{-4}$	1	0.102
$\frac{kpm}{cm\,s\,grd}$	$9.80665 \cdot 10^{2}$	9,81	$2.39 \cdot 10^{-3}$	9.81	1

λ = Coefficient of thermal conductivity, heat or thermal conductivity, thermal conductance.

$$\lambda = \frac{Q * \Delta l}{A * \Delta T}$$

Conversion of Units of Work, Energy (W), Thermal Energy (Q)

Units of Work, Energy (W) Thermal Energy (Q)	Joule J	Kilowatt-Hour kWh	Horse-Power-Hour PSh	Kilopond-Meter kpm	Kilogram-Calorie kcal
Joule J = Watt-Second/Ws = Nm	1	$0.2778 \cdot 10^{-6}$	$0.3774 \cdot 10^{-6}$	0.102	$0.2388 \cdot 10^{-3}$
Kilowatt-Hour kWh	$3.60 \cdot 10^{6}$	1	1.359	$0.367 \cdot 10^{6}$	$0.86 \cdot 10^{3}$
Horse-Power-Hour PSh	$2.65 \cdot 10^{6}$	0.736	1	$0.2702 \cdot 10^{6}$	$0.6329 \cdot 10^{3}$
Kilopond-Meter kpm	$9.80665 \approx 9.81$	$2.724 \cdot 10^{-6}$	$3.702 \cdot 10^{-6}$	1	$2.342 \cdot 10^{-3}$
Kilogram-Calorie kcal	$4.187 \cdot 10^{3}$	$1.163 \cdot 10^{-3}$	$1.58 \cdot 10^{-3}$	$0.427 \cdot 10^{3}$	1

Conversion mm/Inches

mm	inches	mm	inches	mm	inches
0.01	0.0004	0.45	0.0177	0.89	0.0350
0.02	0.0008	0.46	0.0181	0.90	0.0354
0.03	0.0012	0.47	0.0185	0.91	0.0358
0.04	0.0016	0.48	0.0189	0.92	0.0362
0.05	0.0020	0.49	0.0193	0.93	0.0366
0.06	0.0024	0.50	0.0197	0.94	0.0370
0.07	0.0028	0.51	0.0201	0.95	0.0374
0.08	0.0031	0.52	0.0205	0.96	0.0378
0.09	0.0035	0.53	0.0209	0.97	0.0382
0.10	0.0039	0.54	0.0213	0.98	0.0386
0.11	0.0043	0.55	0.0217	0.99	0.0390
0.12	0.0047	0.56	0.0220	1	0.0394
0.13	0.0051	0.57	0.0224	2	0.0787
0.14	0.0055	0.58	0.0228	3	0.1181
0.15	0.0059	0.59	0.0232	4	0.1575
0.16	0.0063	0.60	0.0236	5	0.1969
0.17	0.0067	0.61	0.0240	6	0.2362
0.18	0.0071	0.62	0.0244	7	0.2756
0.19	0.0075	0.63	0.0248	8	0.3150
0.20	0.0079	0.64	0.0252	9	0.3543
0.21	0.0083	0.65	0.0256	10	0.3937
0.22	0.0087	0.66	0.0260	11	0.4331
0.23	0.0091	0.67	0.0264	12	0.4724
0.24	0.0094	0.68	0.0268	13	0.5118
0.25	0.0098	0.69	0.0272	14	0.5512
0.26	0.0102	0.70	0.0276	15	0.5906
0.27	0.0106	0.71	0.0280	16	0.6299
0.28	0.0110	0.72	0.0283	17	0.6693
0.29	0.0114	0.73	0.0287	18	0.7087
0.30	0.0118	0.74	0.0291	19	0.7480
0.31	0.0122	0.75	0.0295	20	0.7874
0.32	0.0126	0.76	0.0299	21	0.8268
0.33	0.0130	0.77	0.0303	22	0.8661
0.34	0.0134	0.78	0.0307	23	0.9055
0.35	0.0138	0.79	0.0311	24	0.9449
0.36	0.0142	0.80	0.0315	25	0.9843
0.37	0.0146	0.81	0.0319	26	1.0236
0.38	0.0150	0.82	0.0323	27	1.0630
0.39	0.0154	0.83	0.0327	28	1.1024
0.40	0.0157	0.84	0.0331	29	1.1417
0.41	0.0161	0.85	0.0335	30	1.1811
0.42	0.0165	0.86	0.0339	31	1.2205
0.43	0.0169	0.87	0.0343	32	1.2598
0.44	0.0173	0.88	0.0346	33	1.2992

Wire Gauges

Gauge	S.W.G		B & S/A.W.G.		Gauge
	inches	mm	inches	mm	
6-0	0.464	11.7856	-	-	6-0
5-0	0.432	10.9728	-	-	5-0
4-0	0.4	10.1600	0.460	11.68	4-0
3-0	0.372	9.4488	0.41	10.41	3-0
2-0	0.348	8.8392	0.365	9.27	2-0
0	0.324	8.2296	0.325	8.26	0
1	0.3	7.6200	0.289	7.34	1
2	0.276	7.0104	0.258	6.55	2
3	0.252	6.4008	0.229	5.82	3
4	0.232	5.8928	0.204	5.18	4
5	0.212	5.3848	0.182	4.62	5
6	0.192	4.8768	0.162	4.11	6
7	0.176	4.4704	0.144	3.66	7
8	0.16	4.0640	0.129	3.28	8
9	0.144	3.6576	0.114	2.90	9
10	0.128	3.2512	0.102	2.59	10
11	0.116	2.9464	0.0907	2.30	11
12	0.104	2.6416	0.0808	2.05	12
13	0.092	2.3368	0.0720	1.83	13
14	0.08	2.0320	0.0641	1.63	14
15	0.072	1.8288	0.0571	1.45	15
16	0.064	1.6256	0.0508	1.29	16
17	0.056	1.4224	0.0453	1.15	17
18	0.048	1.2192	0.0403	1.02	18
19	0.04	1.0160	0.0359	0.912	19
20	0.036	0.9144	0.0320	0.813	20
21	0.032	0.8128	0.0285	0.724	21
22	0.028	0.7112	0.0254	0.645	22
23	0.024	0.6096	0.0220	0.559	23
24	0.022	0.5588	0.0201	0.511	24
25	0.020	0.5080	0.0179	0.455	25
26	0.018	0.4572	0.0159	0.404	26
27	0.0164	0.4166	0.0142	0.361	27
28	0.0149	0.3785	0.0126	0.320	28
29	0.0136	0.3454	0.0113	0.287	29
30	0.0124	0.3150	0.0100	0.254	30
31	0.0116	0.2946	0.00893	0.227	31
32	0.0108	0.2743	0.00795	0.202	32
33	0.0100	0.2540	0.00708	0.180	33
34	0.0092	0.2337	0.00632	0.161	34
35	0.0084	0.2134	0.00562	0.143	35
36	0.0076	0.1930	0.00500	0.127	36
37	0.0068	0.1727	0.00445	0.113	37
38	0.0060	0.1524	0.00397	0.101	38
39	0.0052	0.1321	0.00353	0.0897	39
40	0.0048	0.1219	0.00315	0.0800	40
41	0.0044	0.1118	0.00280	0.0711	41
42	0.0040	0.1016	0.00249	0.0632	42
43	0.0036	0.0914	0.00222	0.0564	43
44	0.0032	0.0813	0.00198	0.0503	44
45	0.0028	0.0711	0.00176	0.0447	45
46	0.0024	0.0610	0.00157	0.0399	46
47	0.0020	0.0508	0.00140	0.0356	47
48	0.0016	0.0406	0.00124	0.0315	48
49	0.0012	0.0305	0.00111	0.0282	49
50	0.0010	0.0254	0.00099	0.0251	50

Conversion °Centigrade / °Fahrenheit

°C		°F	°C		°F	°C		°F	°C		°F
-17.80	0	32.0	10.0[1]	50[1]	122.0[1]	38	100	212	310	590	1,094
-17.20	1	33.8	10.6	51	123.8	43	110	230	316	600	1,112
-16.70	2	35.6	11.1	52	125.6	49	120	248	321	610	1,130
-16.10	3	37.4	11.7	53	127.4	54	130	266	327	620	1,148
-15.56	4	39.2	12.2	54	129.2	60	140	284	332	630	1,166
-15.00	5	41.0	12.8	55	131.0	66	150	302	338	640	1,184
-14.44	6	42.8	13.3	56	132.8	71	160	320	343	650	1,202
-13.89	7	44.6	13.9	57	134.6	77	170	338	349	660	1,220
-13.33	8	46.4	14.4	58	136.4	82	180	356	354	670	1,238
-12.78	9	48.2	15.0	59	138.2	88	190	374	360	680	1,256
-12.22	10	50.0	15.6	60	140.0	93	200	392	366	690	1,274
-11.67	11	51.8	16.1	61	141.8	99	210	410	371	700	1,292
-11.11	12	53.6	16.7	62	143.6	100	212	413	377	710	1,310
-10.56	13	55.4	17.2	63	145.4	104	220	428	382	720	1,328
-10.00	14	57.2	17.8	64	147.2	110	230	446	388	730	1,346
-9.44	15	59.0	18.3	65	149.0	116	240	464	393	740	1,364
-8.89	16	60.8	18.9	66	150.8	121	250	482	399	750	1,382
-8.33	17	62.6	19.4	67	152.6	127	260	500	404	760	1,400
-7.78	18	64.4	20.0	68	154.4	132	270	518	410	770	1,418
-7.22	19	66.2	20.6	69	156.2	138	280	536	416	780	1,436
-6.67	20	68.0	21.1	70	158.0	143	290	554	421	790	1,454
-6.11	21	69.8	21.7	71	159.8	149	300	572	427	800	1,472
-5.56	22	71.6	22.2	72	161.6	154	310	590	432	810	1,490
-5.00	23	73.4	22.8	73	163.4	160	320	608	438	820	1,508
-4.44	24	75.2	23.3	74	165.2	166	330	626	443	830	1,526
-3.89	25	77.0	23.9	75	167.0	171	340	644	449	840	1,544
-3.33	26	78.8	24.4	76	168.8	177	350	662	454	850	1,562
-2.78	27	80.6	25.0	77	170.6	182	360	680	460	860	1,580
-2.22	28	82.4	25.6	78	172.4	188	370	698	466	870	1,598
-1.67	29	84.2	26.1	79	174.2	193	380	716	471	880	1,616
-1.11	30	86.0	26.7	80	176.0	199	390	734	477	890	1,634
-0.56	31	87.8	27.2	81	177.8	204	400	752	482	900	1,652
0.00	32	89.6	27.8	82	179.6	210	410	770	488	910	1,670
+0.56	33	91.4	28.3	83	181.4	216	420	788	493	920	1,688
+1.11	34	93.2	28.9	84	183.2	221	430	806	499	930	1,706
+1.67	35	95.0	29.4	85	185.0	227	440	824	504	940	1,724
+2.22	36	96.8	30.0	86	186.8	232	450	842	510	950	1,742
+2.78	37	98.6	30.6	87	188.6	238	460	860	516	960	1,760
+3.33	38	100.4	31.1	88	190.4	243	470	878	521	970	1,778
+3.89	39	102.2	31.7	89	192.2	249	480	896	527	980	1,796
+4.44	40	104.0	32.2	90	194.0	254	490	914	532	990	1,814
+5.00	41	105.8	32.8	91	195.8	260	500	932	538	1,000	1,832
+5.56	42	107.6	33.3	92	197.6	266	510	950	593	1,100	2,012
+6.11	43	109.4	33.9	93	199.4	271	520	968	649	1,200	2,192
+6.67	44	111.2	34.4	94	201.2	277	530	986	704	1,300	2,372
+7.22	45	113.0	35.0	95	203.0	282	540	1,004	760	1,400	2,552
+7.78	46	114.8	35.6	96	204.8	288	550	1,022	816	1,500	2,732
+8.33	47	116.6	36.1	97	206.6	293	560	1,040	871	1,600	2,912
+8.89	48	118.4	36.7	98	208.4	299	570	1,058	927	1,700	3,092
+9.44	49	120.2	37.2	99	210.2	304	580	1,076	982	1,800	3,272
			37.8	100	212.0				1,000	1,832	3,330

1) **Example:** +50 °C = +122 °F; +50 °F = +10 °C
Calculation: °F = +9 / +5 °C +32; °C = +5 / +9 (°F -32)