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Description of a Pin-Pulling Process with Aid of Dimensional Analysis

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SUMMARY. The complete process of pin-pulling consists of two main parts

1. The thermal behaviour of an electrically heated piece of wire clamped at both ends.
2. The constriction occurring when the wire is overstretched, and many interrelated effects such as change in dimension because of plastic flow, change in heat intensity resulting in different temperature time relations at different places.

Direct mathematical analysis is very difficult; therefore an empirical approach is used, whereby the test results are processed for practical application by means of dimensional analysis. The following process-description shows a way to determine the required current, warming-up time and tensile force for different materials.

Though the experiments have been performed in the sphere of the workshops and thus could not get that kind of attention that is usual for laboratory tests, the question if it is possible to describe this process with aid of dimensional analysis seems to be answered quite well in the affirmative.

RESUME. Le procédé de "pin-pulling" se compose de deux processus principaux:

1. la conductibilité thermique d'un bout de fil chauffé électriquement et fixé par serrage aux deux extrémités,
2. la contraction résultant d'une surtension du fil ainsi que plusieurs effets y relatifs, tels que le changement de dimension en raison du fluage plastique, les variations dans le temps et locales de l'échauffement.

L'application de l'analyse mathématique directe est difficile; c'est pourquoi une méthode empirique a été choisie afin que les résultats des essais soient applicables dans la pratique, et qu'on puisse procéder à l'analyse dimensionnelle.

Le procédé en question montre une voie pour déterminer le courant requis, le temps de chauffage et la tension pour différents matériaux.

Bien que les expériences aient été faites dans les conditions de l'atelier, ce qui implique que toute l'attention souhaitable n'a pas été portée aux résultats, il convient de répondre par l'affirmative à la question s'il est possible de résoudre ce problème à l'aide de l'analyse dimensionnelle.

ZUSAMMENFASSUNG. Das Verfahren des Stiftziehens läßt sich durch zwei wesentliche Erscheinungen kennzeichnen: dem thermischen Verhalten eines beidseitig eingespannten, elektrisch beheizten Drahtes und seiner Formänderung bei Dehnung. Die dabei auftretende Einschnürung ist u.a. abhängig von plastischen Formänderungen und örtlich unterschiedlichen Temperaturverteilungen. Eine unmittelbare mathematische Analyse des Problems ist mit großen Schwierigkeiten verbunden. Daher wurde versucht, die Zusammenhänge zwischen den wichtigsten Einflußgrößen, wie Stromstärke, Erwärmungsdauer und Zugbelastung, für einige Werkstoffe experimentell zu klären und durch empirische Formeln und dimensionslose Kennzahlen auszudrücken. Obwohl die Versuche unter Betriebsbedingungen durchgeführt wurden, und daher kein Anspruch auf wissenschaftliche Exaktheit erhoben werden kann, wurden die Ergebnisse bestätigt.

INTRODUCTION

IN the electronic component industry pins are widely used as parts for radio tubes and transistors. The pins vary in diameter from 0·2 to 2·0 mm and in length from 8 to 72 mm. If they are to be handled by vibratory hoppers and inserting equipment, the pins must meet the following requirements:

The pin must have pointed ends and a sufficiently smooth point surface.

Length variation of the pin must be limited (normal tolerance ±0·2 mm).

The drawing of a pin is shown in Fig. 1.

These pins can be manufactured by various methods such as cutting, rolling and pulling. Of these three methods the last will be dealt with in more detail. The machine used for pulling apart the wire, works on the following principle: A length of wire is clamped between two chucks that can be moved in relation to each other. A current is passed via the chucks through the wire as a result of which its temperature will increase. The heated wire is stretched and separated by moving the chucks apart.

Two different processes are involved, viz.

(a) The thermal behaviour of an electrically heated piece of wire clamped at both ends.

(b) The constriction occurring when the wire is overstretched.

The two processes are interrelated by a number of effects such as change in dimension because of plastic flow, change in heat intensity resulting in different temperature time relations at different places.

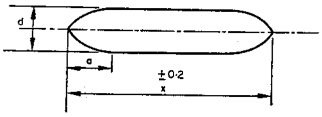

Fig. 1. *Product drawing.*

For different products the material and pin dimensions are given within certain limits.

The practical problem was to find

1. The optimal conditions for the process
2. A practical way to bring the machine setting as close as possible to these conditions.

First the stretching process will be studied; the results will then be worked out to dimensionless numbers. With help of these numbers the setting of the machine in practical cases can be done more systematically.

THE METHOD CHOSEN TO SOLVE THE PROBLEM

As already outlined above, the total process consists of many interrelated effects. Direct mathematical analysis is very difficult; therefore an empirical approach is used whereby the test results are processed for practical application by means of dimensional analysis.

Readers are referred to Refs. [1] and [2] for this method. The use of dimensional analysis for a practical problem depends on the hypothesis that its solution can be expressed in terms of certain variables by means of a homogeneous (dimensional) equation. This hypothesis is based on the trivial fact that physical equations are homogeneous in dimension, that relations can be deduced from these equations and must therefore also be homogeneous in dimension.

However, if an equation is homogeneous in dimension, it can be reduced to a relation between a complete set of dimensionless products (Buckingham theorem). It is obviously necessary that an adequate physical model is used in which all important relevant factors are taken into consideration.

THE PHYSICAL MODEL

Constriction of the wire begins once the stress has exceeded a certain critical value. This stress is temperature dependent and, generally speaking, it may be said that the required critical stress decreases with increasing temperature. As the temperature reaches a maximum in the plane of symmetry, the critical value will be exceeded first in this plane. The physical quantities determining the temperature at a certain place are:

$$\left.\begin{array}{l}\text{(a) the power supplied } P\\ \text{(b) the dissipated heat } Q\\ \text{(c) the heat capacity } C\end{array}\right\}\ \begin{array}{l}\text{all related to the mat-}\\ \text{erial element under}\\ \text{consideration.}\end{array}$$

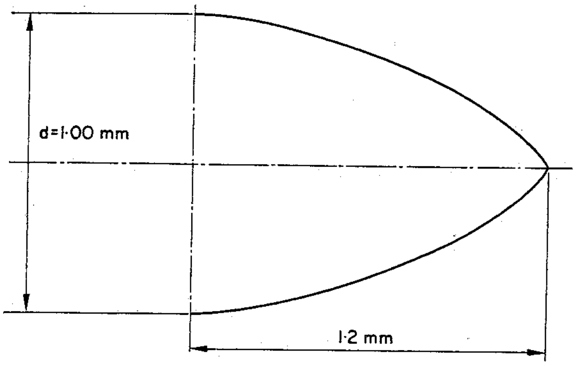

Fig. 2 *Empirically determined ideal shape of the pointed ends.*

If we now consider the total length of wire between clamping points and simplify the situation by using average values of temperature, etc., then the power supplied

$$P_{\text{tot}} = I^2R = \frac{I^2\rho l}{\pi/4d^2} \quad \text{will depend on}$$

1. ρI^2 with ρ = electrical resistivity
2. l $\quad I$ = current
3. d $\quad l$ = distance between the chucks
$\quad d$ = wire diameter.

For the purpose of finding dimensional quantities this simplification may be justified. The wire temperature is considered to be only variable with x and the time t.

The dissipated heat for an element in the middle of the wire, $Q = \lambda.A.\frac{dT}{dx}.t$, will depend on

1. λ with λ = heat conductivity
2. T $\quad T$ = temperature of the middle of the wire
3. t $\quad t$ = warming-up time
4. l $\quad l$ = distance between the chucks
5. d $\quad d$ = wire diameter.

The constriction is determined by

1. the deformation energy / unit volume, E
2. the tensile strength at T°C, σ_T

$$E = \frac{F}{A} \cdot \varepsilon$$

The deformation energy depends on:

1. F with F = applied force
2. A $\quad A$ = surface of a plane, perpendicular to the axis of the wire
3. ε $\quad \varepsilon$ = strain.

In considering these simplified equations, the following variables were considered to be of importance in the dimensional analysis.

1. ρI^2, W. m $\qquad M.L^{+3}.T^{-3}$

   It is permissible to combine I with ρ, because these are the only variables containing the electrical basic units of charge or current.
2. E = deformation energy / unit volume, Nm/m^3 $\qquad M.L^{-1}.T^{-2}$
3. C = heat capacity / unit volume, Nm/m^3°C $\qquad M.L^{-1}.T^{-2}.\theta^{-1}$
4. λ = heat conductivity, Nm/msec°C $\qquad M.LT^{-3}.\theta^{-1}$
5. d = wire diameter, m $\qquad L$
6. l = distance between the chucks, m $\qquad L$
7. T = temperature of the middle of the wire $\qquad \theta$
8. t = warming-up time, sec. $\qquad T$
9. σ_T= tensile strength of the wire at T°C $\qquad M.L^{-1}.T^{-2}$

From these variables the following complete set of dimensionless products can be formed.

$$V_1 = \frac{\lambda.t}{Cl^2}$$

Table 1. *Dimensional matrix of the variables*

	E	ρI^2	t	T	d	C	λ	l	σ_T
Mass	1	1	0	0	0	1	1	0	1
Length	−1	3	0	0	1	−1	1	1	−1
Time	−2	−3	1	0	0	−2	−3	0	−2
Temperature	0	0	0	1	0	−1	−1	0	0

$$V_2 = \frac{\lambda.Tl^2}{\rho I^2}$$

$$V_3 = \frac{l}{d}$$

$$V_4 = \frac{F}{A\sigma_T}$$

$$V_5 = \frac{\rho I^2 t}{Fl^2}$$

The following physical significance can now be given to the dimensionless numbers.

V_1 = dissipated heat / heat capacity
V_2 = dissipated heat / generated heat
V_3 = geometrical proportion
V_4 = force applied / force required
V_5 = energy supplied / mechanical energy.

In order to determine the relations between these numbers, it will be necessary to measure some variables by tests on the production machines.

From the literature (see [3] and [4]) the following may be derived as a function of temperature.

1. the specific electrical resistivity
2. the specific heat
3. the heat conductivity
4. the tensile strength at temperature T.

The other variables are measured at the machine. The following five materials were at our disposal.

1. Nickel
2. Nickel Iron 50/50
3. Nickel plated Iron
4. Copper + 2% Ag
5. Molybdenum

All with a diameter of 1 mm.

Table 2. *Results of measurement*

	Nickel	Nickel Iron 50/50	Nickel-Plated Fe	Copper + 2% Ag	Molybdenum
I_{av}(A)	396	240	297	1131	707
F(N)	80	70	70	75	110
T(°C)	572	607	465	310	705
t(sec)	0·08	0·08	0·08	0·04	0·04
$C.10^6$ (Nm/m^3°C)	4·63	4·58	5·02	3·74	2·78
λ(Nm/msec°C)	50·2	21·4	42	369	113
$\rho 10^8$(m)	36·5	11·5	53	88	23·3
$\sigma_T.10^6$ (N/m^2)	250	350	250	88	240
$l.10^3$(m)	2	1·94	1·94	2·0	2·24

DIMENSIONLESS NUMBERS THAT ARE USEFUL IN PRACTICE

The dimensionless numbers V_1 to V_5 incl. are calculated for the five materials mentioned above and are shown in the table below.

When shown on log log paper the relations are linear between

V_4 and V_5 (Fig. 3),

V_2 and V_5 (Fig. 4), and

V_1 and V_2 (Fig. 5).

The following values were obtained.

$$V_4 = 5{\cdot}4\ V_5^{-1},$$

$$V_2 = 271\ V_5^{-2}, \text{ and}$$

$$V_1 = 0{\cdot}13\ V_2^{0\cdot8}$$

Substitution in the equations leads to the following expressions.

$$\frac{F}{A\sigma_T} = 5{\cdot}4\left(\frac{\rho I^2 t}{Fl^2}\right)^{-1}$$

$$\frac{\lambda T l^2}{I^2} = 271\left(\frac{\rho I^2 t}{Fl^2}\right)^{-2}$$

$$\frac{\lambda t}{Cl^2} = 0{\cdot}13\left(\frac{\lambda T l^2}{\rho l^2}\right)^{0\cdot8}$$

The variables occurring in the above relations are:

1. $\lambda = \lambda(T)$ °
2. $C = C(T)$ °
3. $\rho = \rho(T)$ °
4. σ_T °
5. T °
6. l *
7. d *
8. $A = \pi/4d^2$ *
9. F
10. t
11. I

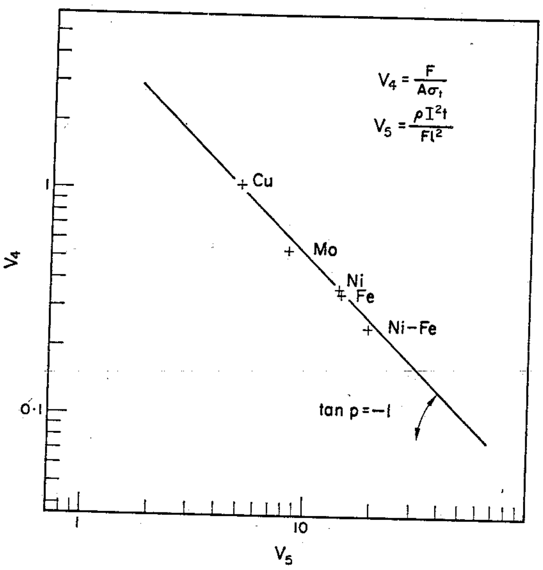

Fig. 3. The relation between the dimensionless numbers V_4 and V_5.

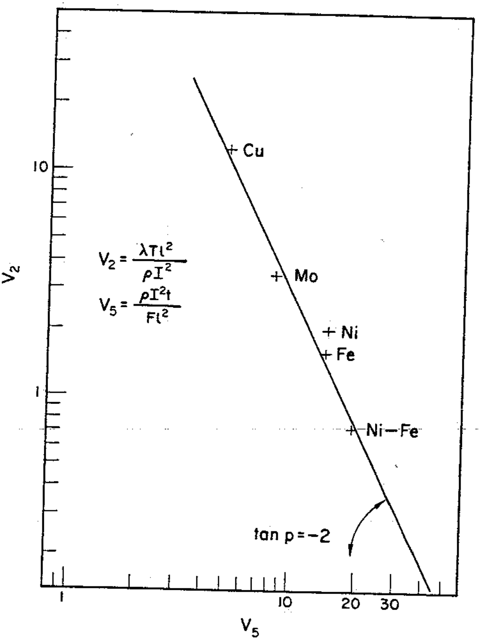

Fig. 4. The relation between the dimensionless numbers V_2 and V_5.

Table 3. Values of the dimensionless numbers

	V_1	V_2	V_3	V_4	V_5
Ni	0·218	2·00	0·463	0·40	14·3
NiFe	0·1	0·732	0·515	0·246	19
Fe	0·178	1·58	0·515	0·356	14·1
Cu	0·986	12·2	0·5	1·08	5·0
Mo	0·325	3·42	0·446	0·53	8·4

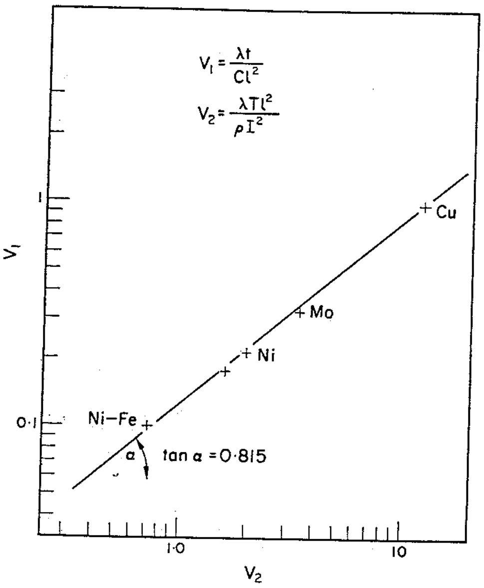

Fig. 5. The relation between the dimensionless numbers V_1 and V_2.

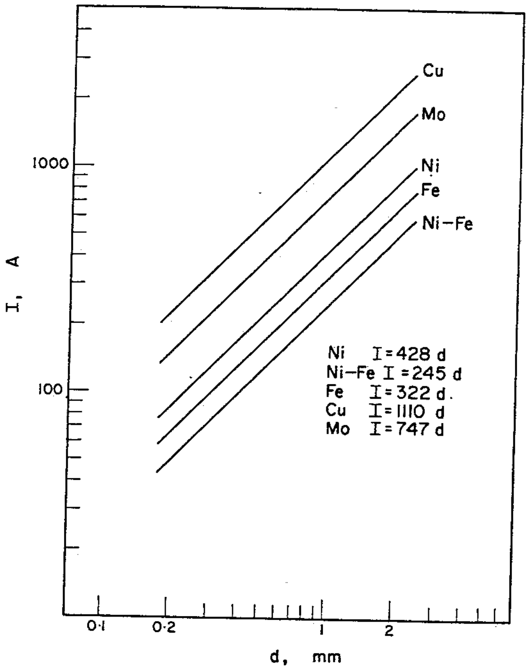

Fig. 6. The relation between the current I and the diameter d.

Table 4. F, t and I as a function of the diameter, d, mm

	I (A)	t(sec)	F(N)
Ni	428 d	7·41 10^{-2} d	98 d^2
NiFe	245 d	7·93 10^{-2} d	77 d^2
Fe	322 d	7·25 10^{-2} d	23·3 d^2
Cu	1110 d	3·52 10^{-2} d	141 d^2
Mo	747 d	3·91 10^{-2} d	108 d^2

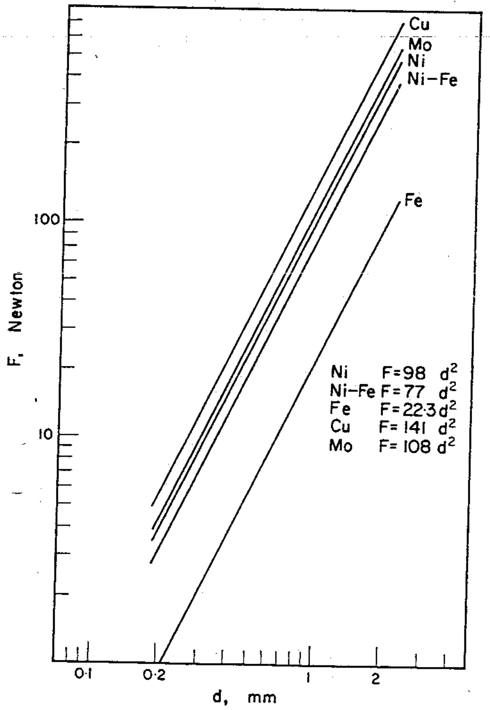

Fig. 7. The relation between the tensile force F and the diameter d.

As a practical example of the use of experimental data the following may serve.

The starting point is wire of a certain diameter. What values must the current, the warming-up time, the tensile force and the distance between the chucks have to obtain the desired shape of the pointed ends? If we proceed from wire with a given diameter, the magnitudes marked with * are given. If we, moreover, assume that the temperature as measured is the only one at which the process can properly take place, the temperature i.e. the magnitudes marked with ° are also determined. However, there are still three equations and three unknown variables, so F, t and I can be calculated as a function of the diameter.

We find: $I = I(d)$ from Fig. 6,

$F = F(d)$ from Fig. 7 and

$t = t(d)$ from Fig. 8.

The results of the above data with $d/l \approx 0{\cdot}5$ are given below.

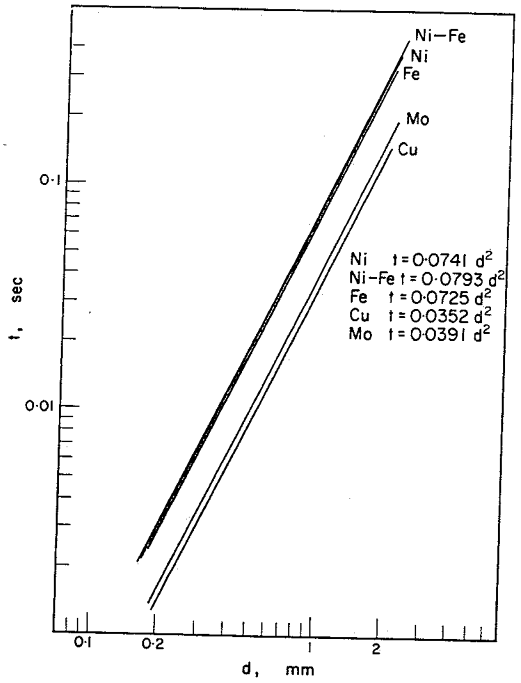

Fig. 8. The relation between the warm-up time t and the diameter d.

DISCUSSION OF THE RESULTS

From this limited amount of measuring points, it cannot be expected that more accurate proportions can be determined between the dimensionless numbers. The graphical working out for that purpose has to be limited to the primary stage. Moreover, the values for σ_T in the various text books vary rather considerably.

Nevertheless in practice these numbers give some improvement over the trial and error method previously employed.

CONCLUSION

The foregoing dimensional analysis has shown a way to determine the required current, warming-up time and tensile force for different materials. In order to decrease the inaccuracy in the data available more experimental work of the type described has to be performed to arrive at sufficiently accurate results. In this further set of investigations, it will be necessary not only to increase the number of materials, but also to vary the diameter.

It may turn out that with these materials a useful shape of the pointed ends can also be obtained at temperatures other than those at which the experiments were done. However, this could not be verified from test results taken from the available production machine, which was not in any way intended for fundamental experiments. Further tests on machines built specifically for experiments may be useful for this purpose.

REFERENCES

1. Langhaar, H. L., *Dimensional Analysis and Theory of Models*. John Wiley (1960).
2. Huntley, H. E., *Dimensional Analysis*. MacDonald (1952).
3. Goldsmith, A., Waterman, Th. E. and Hirschhorn, H. J., *Handbook of Thermophysical Properties of Solid Materials*, Vol. 1. Macmillan (1961).
4. *Zahlenwerte und Funktionen aus Physik, Chemie, Astronomie, Geophysik und Technik*, IV Band, 2e Teil. Springer (1957).

DISCUSSION

Prof. Alexander

Have the authors given any consideration to the possibility of applying their methods of analysis to a pin-*pushing* type of process, i.e. to upsetting a rod by electrical heating?

Author's reply:

We had no intention of developing a new process, but intended a particular study of an existing procedure for pin manufacturing, i.e. pin-pulling. From that point of view we were not interested in studying pin-pushing.

The aim of our study was the improvement of the control of the pin-pulling process under various circumstances (diameter, etc.). For this study we used the method of dimensional analysis. In a dimensional analysis, however, there is no objection to replacing a tensile force by a compressive force; this does not change the basic ideas of the analysis. In addition to the foregoing we ignored the final shape of the work piece.

The main difficulty for an exact analysis of the pin-pulling process is the determination of the shape of the constricted wire, as derived from the theories of plasticity. We assume that in a study of warm pushing the same problem will be met. Therefore, for our study, we choose the empirical method mentioned and started from a technically well-defined process and shape of the pin point. In an exact analysis of the pushing process it will be perhaps possible to determine the maximum diameter of the pushed wire as directly correlated with the final shape of the wire, maybe in combination with the proportional shortening of the wire length. In comparison with a pulling process, a pushing procedure has still another difficulty. In pulling, the tensile force is limited by the rupture of the wire. In the pushing process the increase of force has no such limit. Such a limit can be built in by the application of stops in the pushing equipment. But those stops interfere with the process of shape forming and will also add their consequences in the application of the dimensional analysis.