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NORMAN W. CURTIS
Vice President-Engineering & Construction
821-5381

Mr. Olan D. Parr
Chief
Light Water Reactors Branch No. 3
Division of Project Management
U.S. Nuclear Regulatory Commission
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This transmittal is made in response to your letter of April 28, 1978 regarding the witholding of the KWU proprietary documents from public disclosure.

Very truly yours,

NW Curtis

N.W. Curtis
Vice President-Engineering & Construction

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TRANSLATION

TITLE : — as translated into ENGLISH

CALCULATION MODEL TO CLARIFY THE PRESSURE OSCILLATIONS IN THE SUPPRESSION CHAMBER AFTER VENT CLEARING

— as translated from GERMAN

BERECHNUNGSMODELL ZUR K
DER KONDENSATIONSKAMMER

AUTHOR/S/ : WEI
SCH

SOURCE : AEG
29
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Translated AUGUST 1977

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NUCLEAR REACTORS

Pfm., 29 March 1972
Dr. Wei/ru
Report No. 2208

CALCULATION MODEL TO CLARIFY THE
PRESSURE OSCILLATIONS IN THE
SUPPRESSION CHAMBER AFTER VENT CLEARING

Prepared:	/s/	/s/	Dr. Weisshäupl/Schall E3/E 2
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Summary

To explain the periodic pressure variations observed in KWW underneath the relief pipe of the suppression chamber and in GwH in the scram tank, a physical model is set up. This model consists of the assumption that during the vent clearing process in the relief pipe the air cushion situated between the outflowing steam and the water slug is highly compressed and, when it emerges from the pipe, begins to expand suddenly because of its over-pressure. It is then compressed again by the pressure of the water mass loading it from above, etc., thereby creating an oscillation process.

The excellent qualitative and quantitative agreement between the theoretical and experimental pressure variations allows us to conclude that the observed periodic pressure fluctuations can be described by the assumed physical model of the oscillation of the system consisting of air bubble and water mass loading it from above.

1. Introduction

Before the steam "braid" is produced during clearing through the relief pipe, the water slug situated in the pipe is first expelled, forming a highly compressed air cushion between the water slug and the afterflowing steam. When that air cushion emerges from the pipe, it begins to expand again suddenly in order to come into equilibrium with the surrounding pressure (which is composed of the pressure in the suppression chamber and the hydrostatic pressure).

The suppression chamber water mass loaded by the emerging air cushion is driven upward until the influence of the gravitational force and of the underpressure forming in the air bubble as time passes (which is produced by the continued upward movement of the water resulting from the mechanical inertia principle) leads to a reversal of the process and the air bubble is compressed again by downward motion of the water mass. That is followed by renewed expansion, etc., etc. The air bubble - water mass system under consideration thus represents an oscillatory system whose oscillation persists until the air bubble has risen to the water's surface and breaks there or until the oscillation amplitude becomes negligibly small due to strong damping and lateral outflow of the water that is thrown upward.

In the following we now set up a highly simplified model of this oscillation process and compare the results obtained from it with

the poriodic prossure variations observed oxperinentally in KWW and in GWH [1].

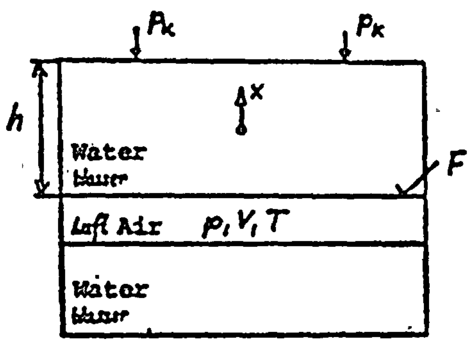
[1] Rupp, Eismar, Pohl: KWW - Results of the rolief valve tests with the special instrumentation. AEG-E3-2160

2. Oscillation of the air bubble - water mass system

2.1 Equation of motion

To calculate the oscillatory behavior of the air bubble and the water mass loading it from above, we make the following highly simplified assumptions:

a) After emerging from the relief pipe, the air bubble has the shape of a flat cylinder (see Figure below).



p_K = pressure in suppression chamber

b) The air bubble does not rise to the surface of the water during the oscillation process (the influence of this process is taken into consideration by a parametrization of the air bubble's submergence).

c) The air bubble expands only in the vertical direction (assuming a flat cylinder, the horizontal expansion is approximately negligible relative to the vertical expansion).

d) The water mass lying above the bubble does not change its shape during the oscillation process (thus, no water flows

away laterally during the lift, and no water flows in from the side during the drop).

From the center-of-mass theorem we obtain the equation of motion of the water mass:

$$m\ddot{x} = -mg + (p - p_K) \cdot F \quad . \tag{1}$$

The acceleration of the water mass m is maintained by gravitation, the pressure p of the air bubble on the water mass above it, and the suppression chamber pressure p_K. x is the coordinate of the center of mass of the water mass, F is the boundary surface area between the air bubble and water mass.

Since the oscillation proceeds rapidly enough, we can assume an adiabatic change of state of the gas. Therefore, the relation between the instantaneous state (p, V, T) and the initial state (p_o, V_o, T_o) which prevails immediately after the expulsion of the air bubble from the relief pipe reads:

$$p \cdot V^{\varkappa} = p_o \cdot V_o^{\varkappa} \tag{2}$$

For air, κ = [illegible]

The change of the gas volume from V_o to V corresponds exactly to the lift of the water mass. Thus:

$$V = V_o + F \cdot x, \tag{3}$$

from which we obtain for the pressure from Eq. (2):

$$p = \frac{p_0}{\left(1 + \frac{F}{V_0} \cdot x\right)^{\varkappa}} \tag{4}$$

If we now express the state variable V_0 in terms of the state variables p_a, V_a for the initial state of the quantity of air which is present before the beginning of the vent clearing process:

$$p_0 \cdot V_0^{\varkappa} = p_a \cdot V_a^{\varkappa} , \tag{5}$$

then we get for the pressure p:

$$p = \frac{p_0}{\left[1 + \frac{(p_0/p_a)^{1/\varkappa}}{V_a/F} \cdot x\right]^{\varkappa}} . \tag{6}$$

If we insert this expression into the differential equation (1) we finally obtain for the equation of motion:

$$\ddot{x} = -g - \frac{p_K}{\rho_W h} + \frac{p_0}{\rho_W h} \cdot \left[1 + \frac{(p_0/p_a)^{1/\varkappa}}{V_a/F} \cdot x\right]^{-\varkappa} \tag{7}$$

in which we have set $m = \rho_W F h$ for the mass m of the water (ρ_W is the density of the water, h is the submergence of the air bubble).

In this differential equation of second order, the variables p_o, h, F and V_a appear as parameters (p_a = [illegible] kg/cm^2, p_K = [illegible] kg/cm^2). The equation can be solved readily by a numerical method (Runge-Kutta, Euler, etc.) and leads to the center-of-mass motion of the water mass as a function of time: x = x(t). The dependence of the pressure on time, p = p(t), can finally be determined from Eq. (6).

2.2 Performance of the numerical calculation

The input quantities in Eq. (7) consist of measurable data (maximum pressure, normal air volume) and also of data resulting from the assumption of the calculated model. In order to include quantitatively the effect of those calculation assumptions, parameter calculations were performed starting from a reference case.

2.2.1 Data

The data for the reference case were:

a) Initial pressure p_o:

[redacted]

corresponding to a measurement of the maximum pressure

b) Specific weight of the water:

ρ_W = [redacted] kg/m^3

c) Height of the water cushion h:

h = [redacted]

The air bubble was assumed to be at the height of the end of the relief pipe. Therefore,

$h \mathrel{\hat{=}}$ submergence of the relief pipe

d) Surface area of the cylindrical steam bubble:

It was assumed that the steam bubble expands cylindrically as far as the edge of the suppression chamber. Therefore:

$F = \frac{\pi}{4} \ d^2$ [redacted]

[redacted]

e) Normal air volume V_a:

The air volume in the relief pipe was determined in AEG-E3/E2-2160 to be

[redacted]

With this data we obtain for the constant:

[redacted]

The numerical evaluation was accomplished by using the Runge-Kutta method with a time sharing system. The result of the calculation is illustrated in Figure 2. A comparison with the measured pressure variation (Figure 1) reveals good qualitative agreement and thus provides the sought proof that the observed oscillations were interpreted correctly.

For a quantitative interpretation it is necessary to perform several (parameter) calculations to exhibit the influence of the various influential parameters on the oscillation data.

2.2.2 Parameter calculation

The input quantities into the oscillation model are based partially on measurements and partially on assumptions concerning the shape of the air bubble. To determine the influence of this "arbitrary" initial data, it is necessary to perform a parameter calculation.

The following quantities were varied in the parameter calculation:

$\frac{P_o}{P_a}$: Pressure ratio of the blow-out process

h : Distance of the air bubble from the water surface

$\frac{V_a}{F}$: This quantity represents a form factor, since, in addition to the known quantity V_a, it also contains an assumption concerning the spreading of the surface area (cylindrical).

A survey of the calculations performed is given in Table 1.

The variation of the pressure in the air bubble and the displacement amplitude of the water layer for a half oscillation period are illustrated for the various calculations in Figures 3-11. From them we can determine the various characteristic magnitudes characterizing the oscillation:

Maximum vertical displacement

Minimum pressure ratio

(Half) oscillation period and oscillation frequency

The corresponding values for the computation runs are listed in Table 1.

A graphical evaluation was performed in Figure 12.

3. Discussion

The frequency is of primary interest in connection with the measured pressure oscillations, since only through it is it possible to confirm quantitatively the calculation results. (The maximum pressure is an input quantity into the calculation; the vertical displacement of the water was not measured.)

The only "arbitrary" input quantity into the computation model was the bubble's surface area F, which contained a hypothesis concerning the (cylindrical) shape of the air bubble. The influence of the corresponding parameter (it involves the parameter V_a/F) on the frequency therefore provides an indication of a possible quantitative agreement between calculation and measurement. As follows from Figure 12a, such agreement does exist for a relatively flat air-bubble shape with a diameter of

$$d = \frac{4}{\pi} \sqrt{F}.$$

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This result is confirmed qualitatively by the observed rapid spreading of the air expelled during the blow-out.

The bubble's submergence h decreases during the oscillation process. It follows from Figure 12a that this (as in the tests) is associated with a sharp increase of the frequency and therefore provides another confirmation of the correctness of the physical model. The maximum pressure p_o (or the ratio p_o/p_a) is fixed by the blowdown process and can only be changed by design measures. As expected, this quantity influences primarily the minimum pressure ratio and the maximum vertical displacement (Figures 12b and 12c).

4. Conclusion

The purpose of the study was to provide computational proof that the pressure oscillations occurring in the condensation tests are related to the amount of air expelled at the beginning of the blowdown.

A physical model was set up and calculated in accordance with the concept that the expelled air, which is at an overpressure relative to the steady-state conditions, forms a cylindrical bubble and represents an oscillatory structure together with the water layer lying above it.

Using this simplified model and the measurable input magnitudes, and assuming a particular dimension of the cylindrical air bubble, both qualitative and quantitative agreement was found between the measured and calculated oscillation mode and the frequency behavior of the oscillation was correctly predicted.

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Table....1....

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Figure...1....

Bild 2:

Berechneter Druckverlauf unterhalb des Entlastungsrohres (in der Luftblase) - Referenzfall

Figure 2

Calculated variation of pressure beneath the relief pipe (in the air bubble) - Reference case

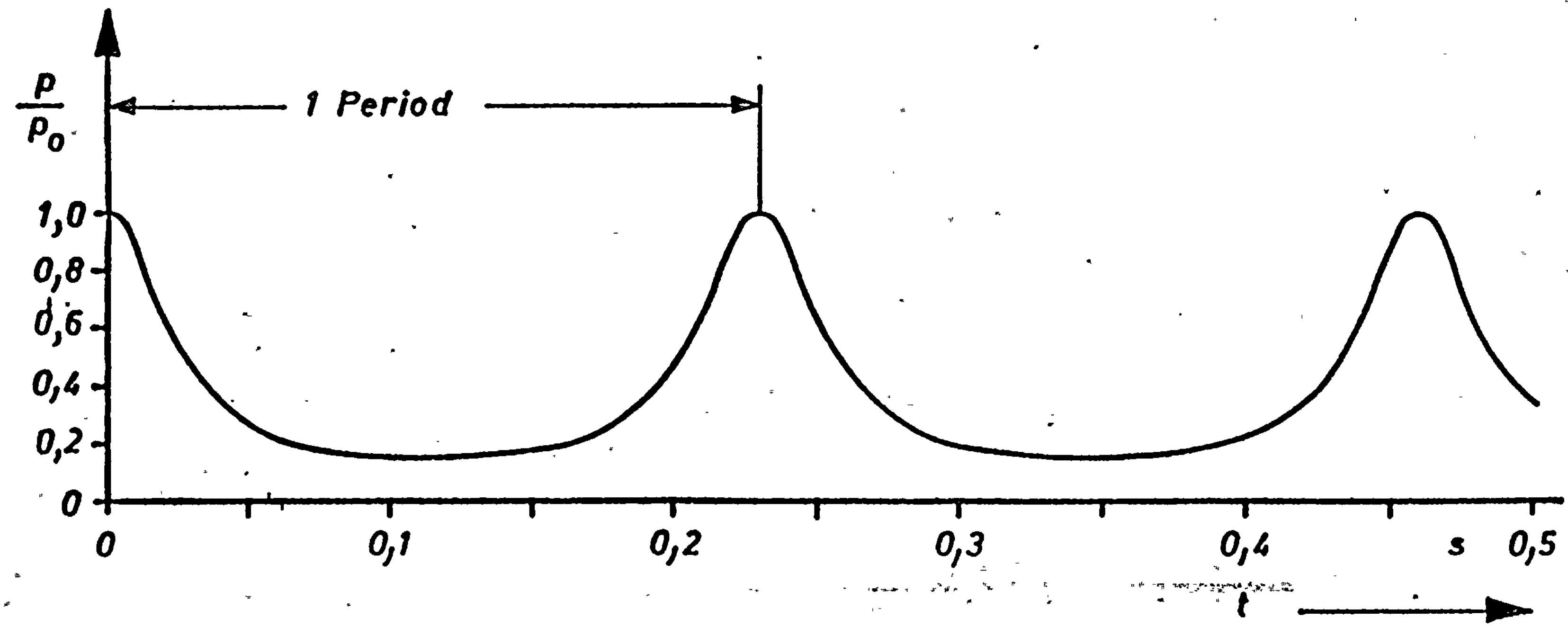
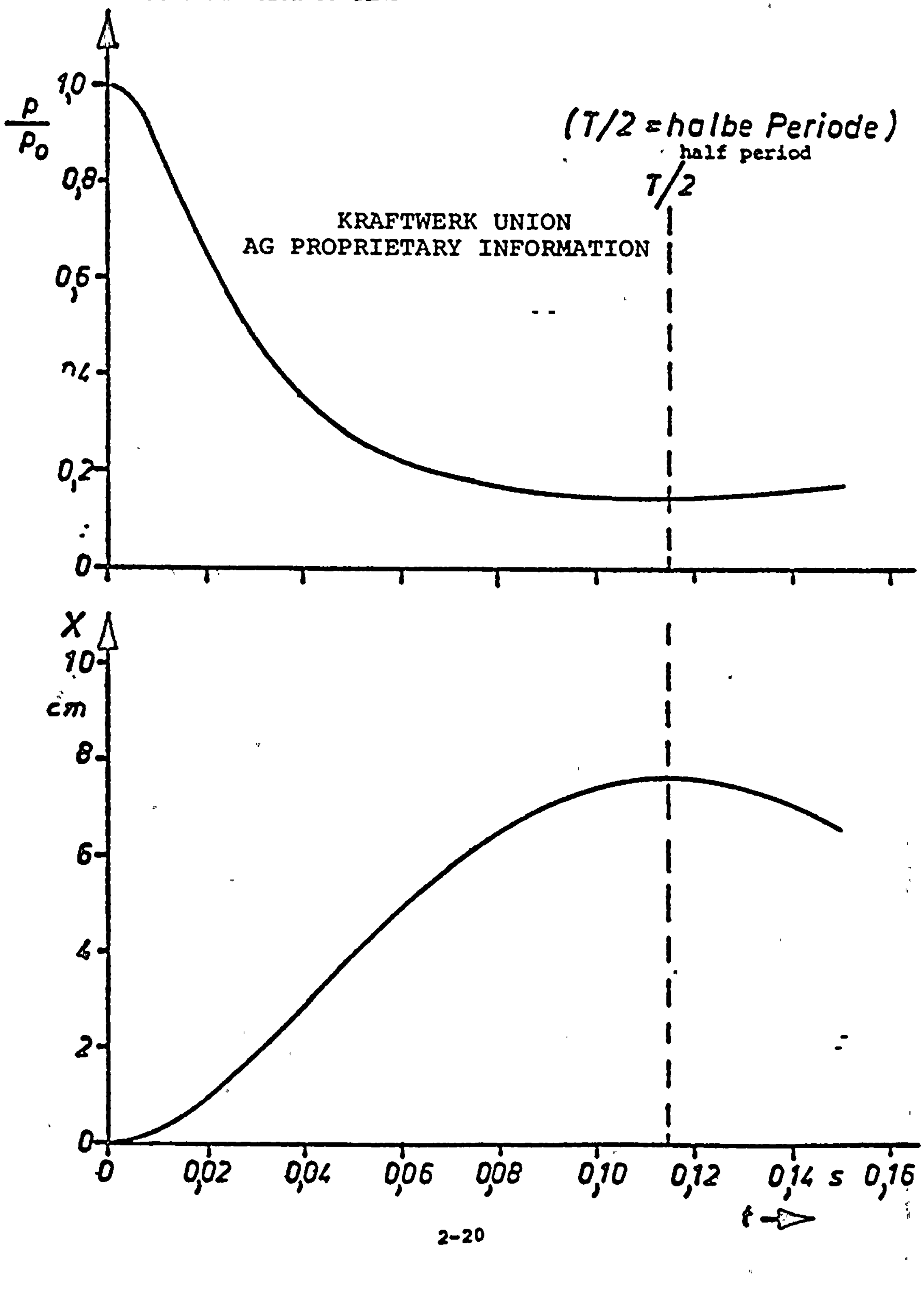


Figure 3

Variation of the pressure relative to the initial pressure and of the vertical displacement of the water as a function of time



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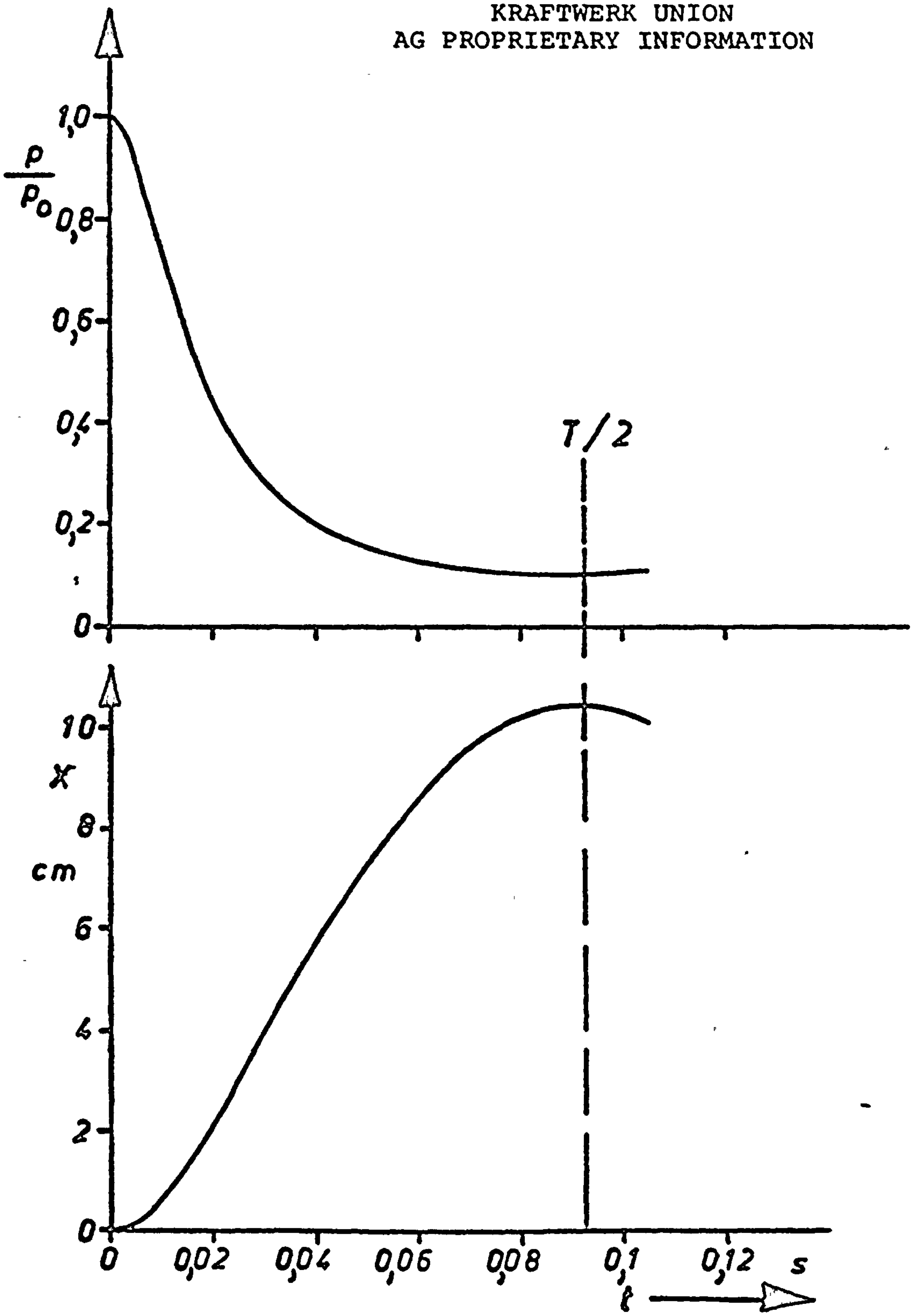

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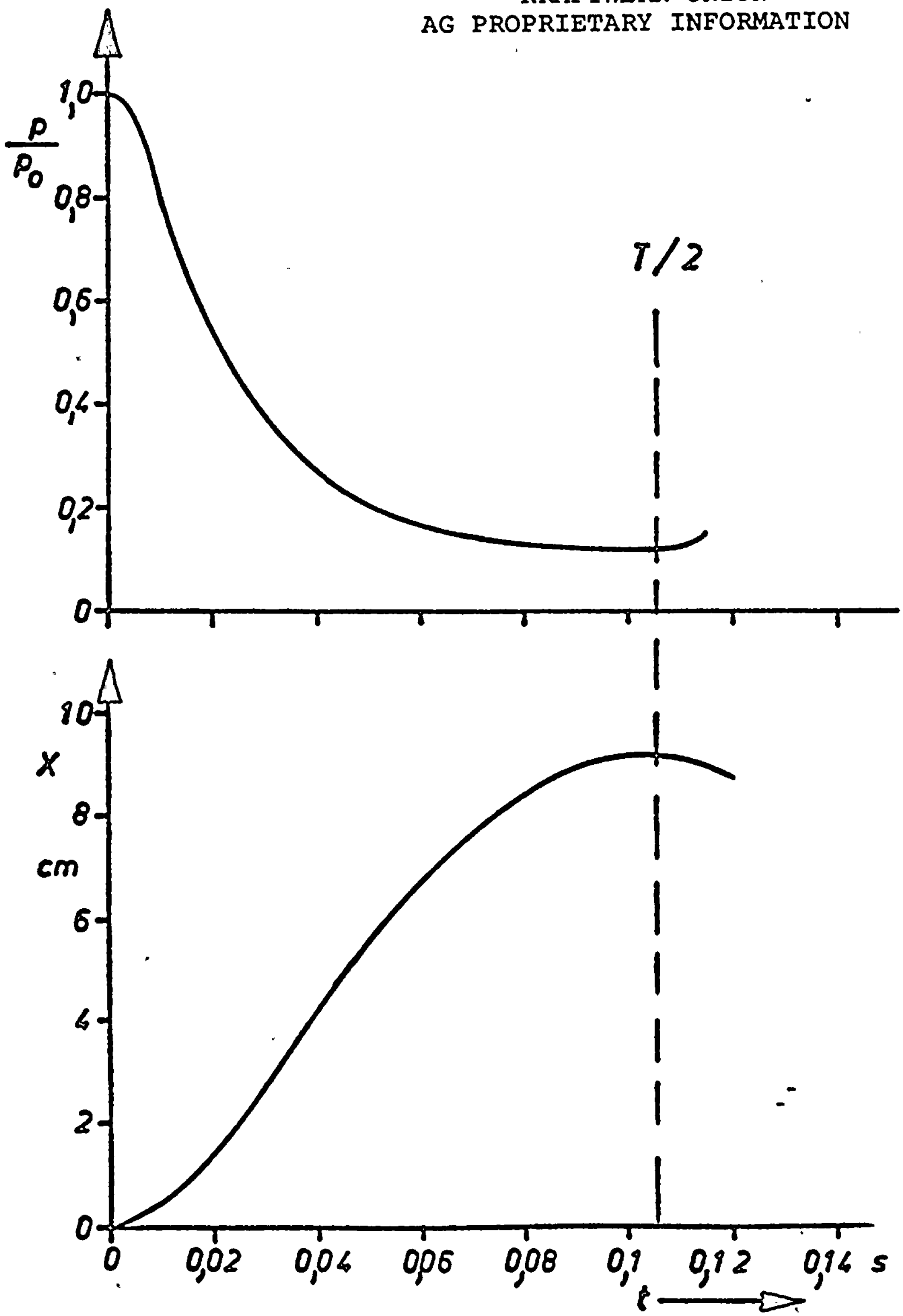

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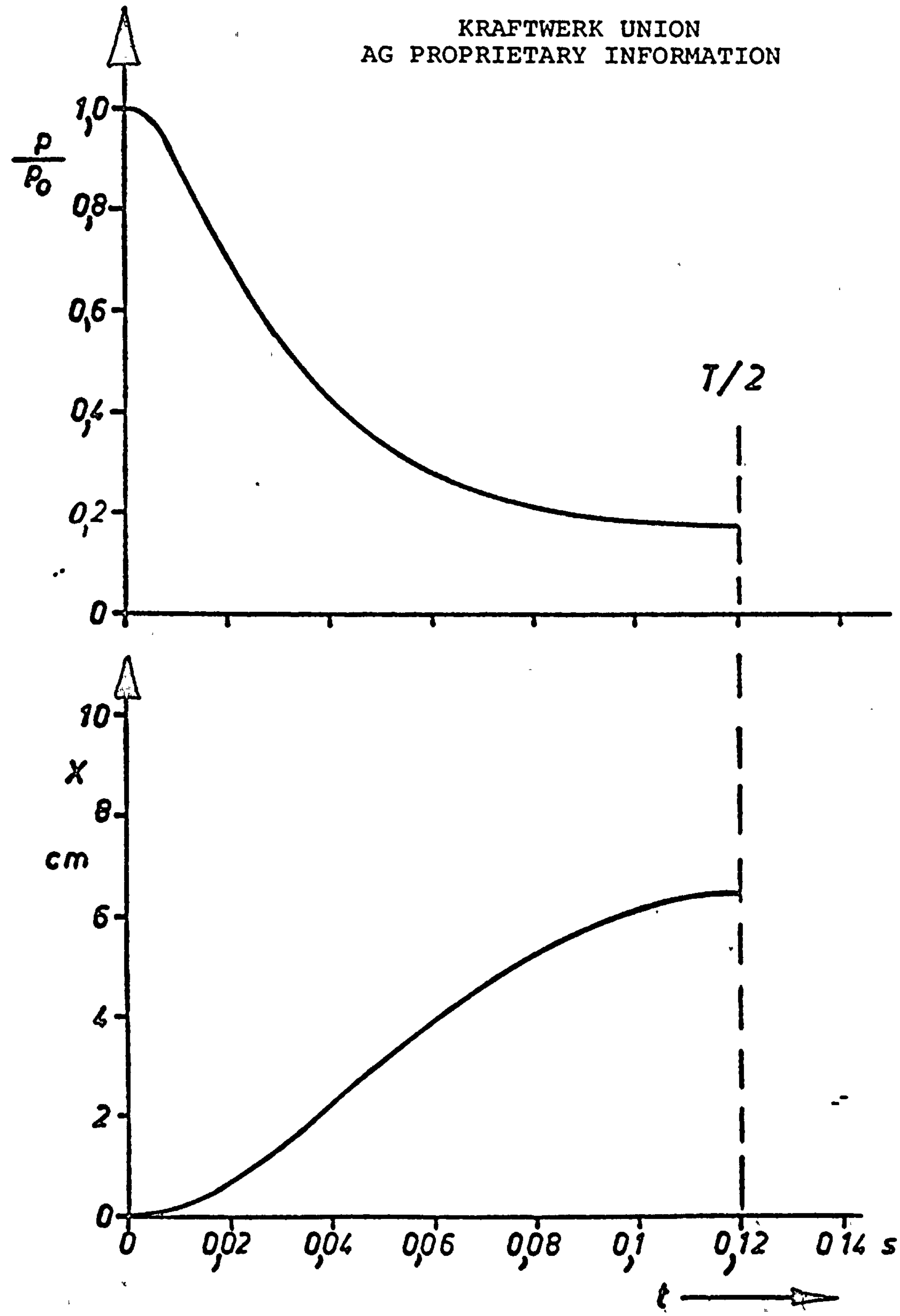

Figure 7

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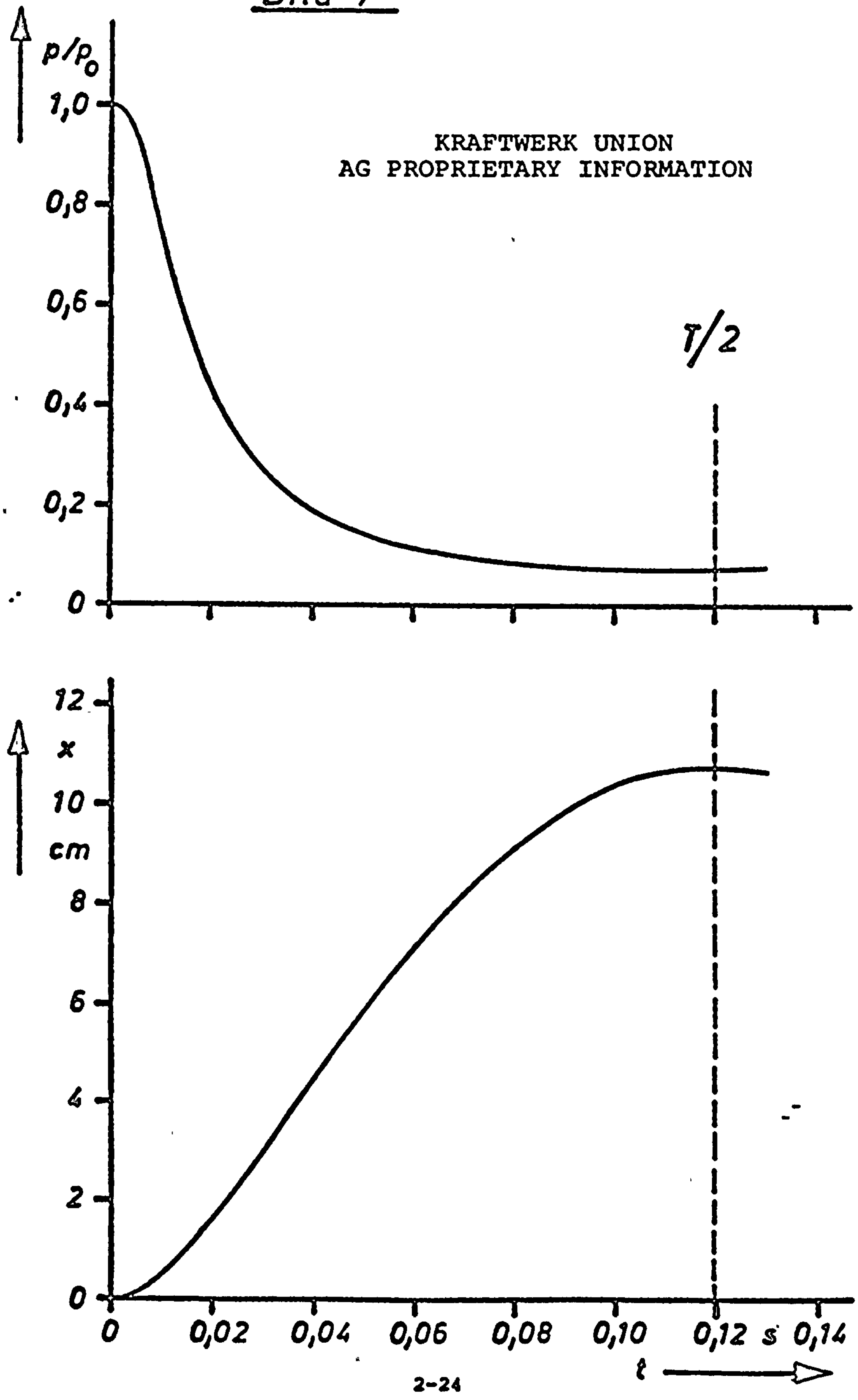

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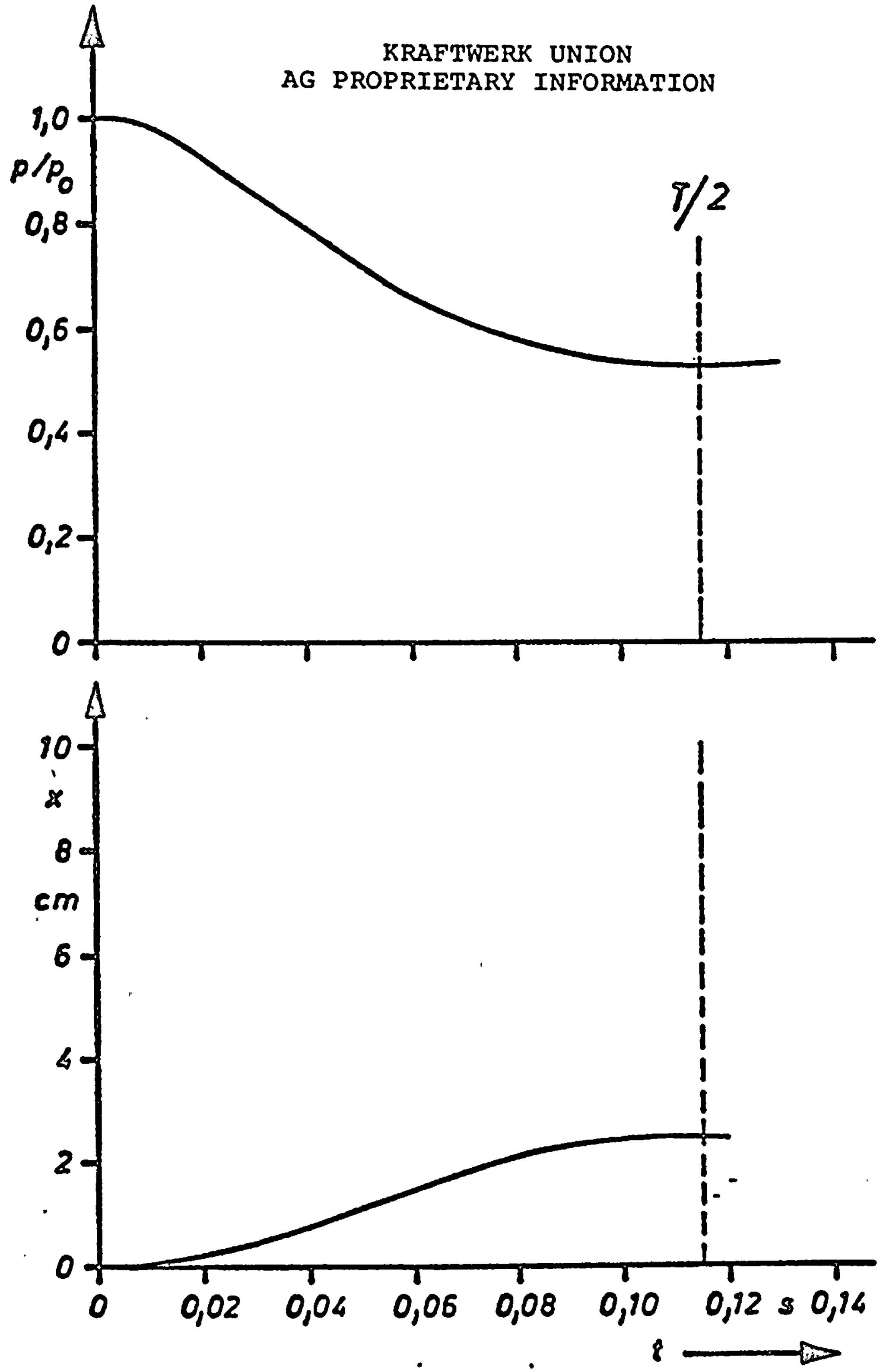

Figure 9

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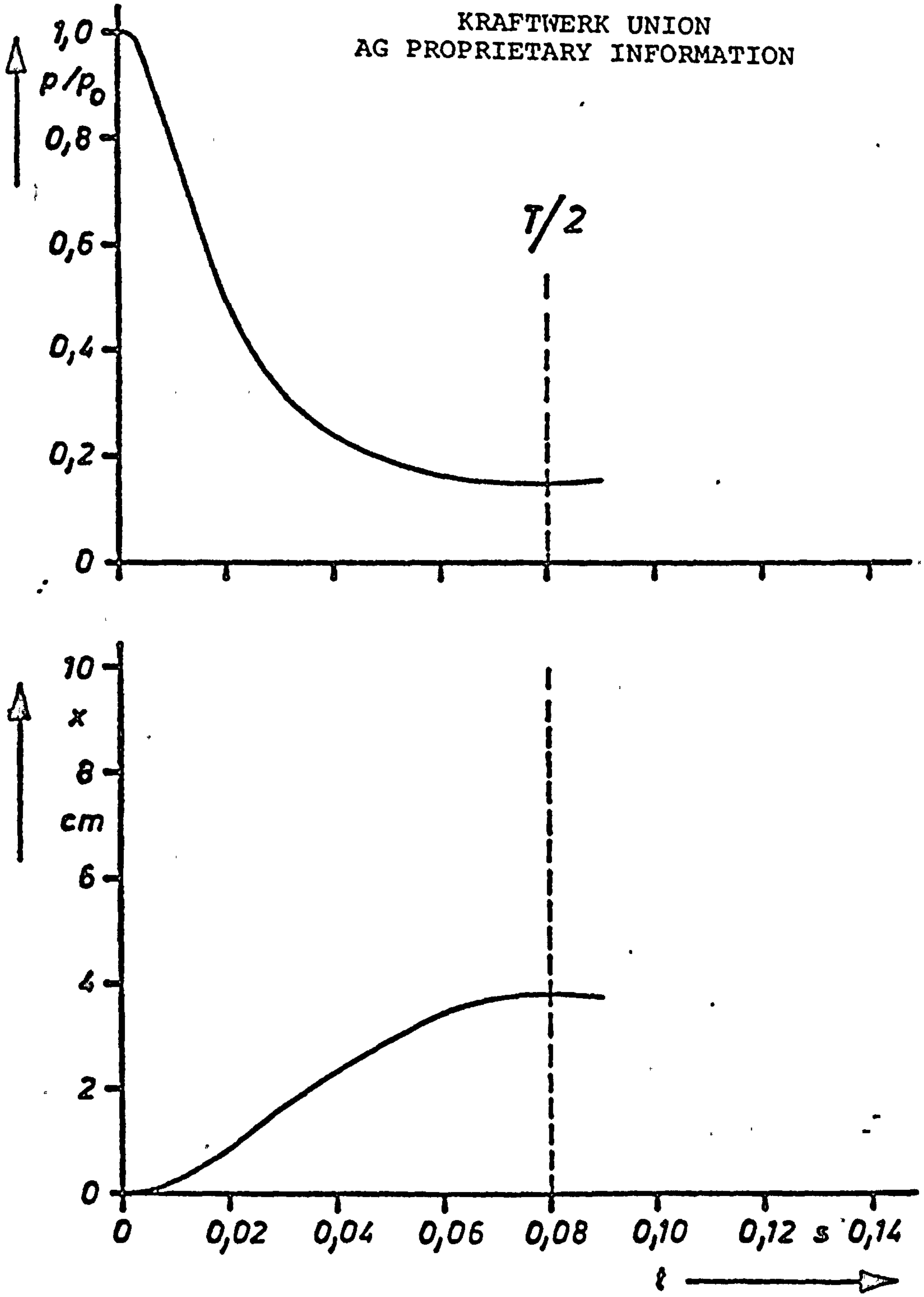

Figure 10

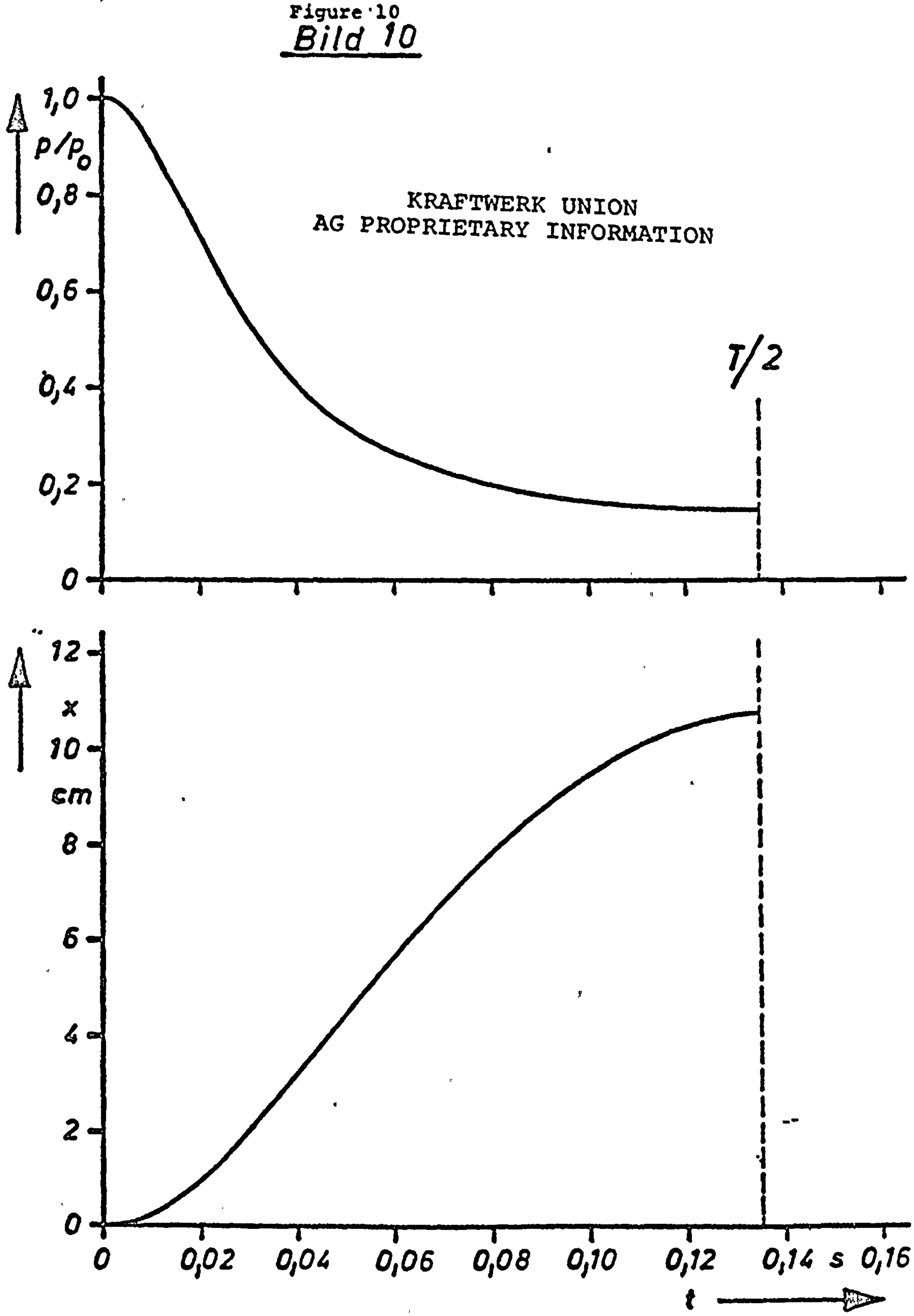

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Figure 11

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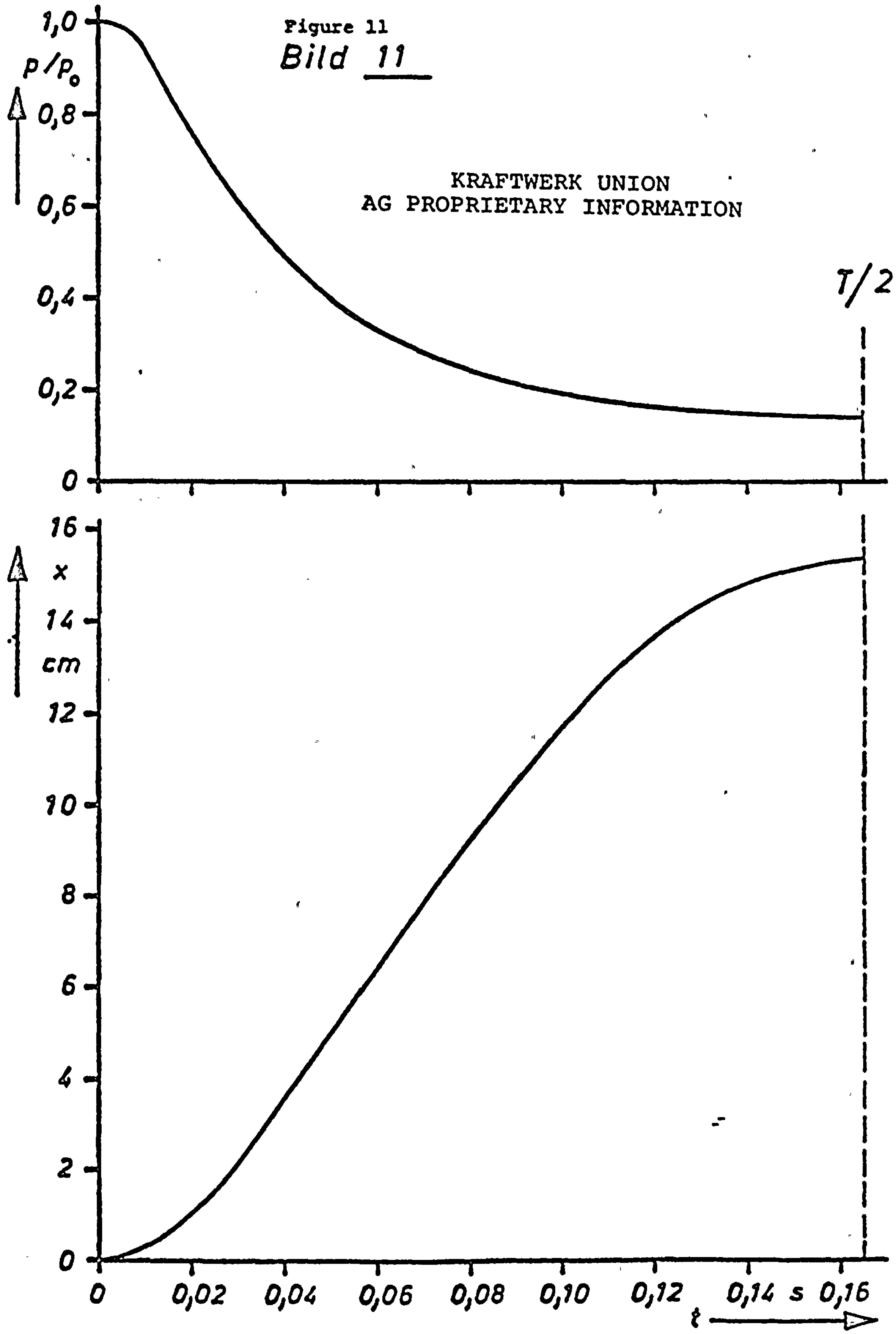

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Figure....12...