DEVELOPMENT OF A TECHNIQUE
TO MEASURE INK TACK

by

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ABSTRACT

It has long been recognized that an ink property of central importance is its ability to support tensile stresses as the printing plate and the printed surface separates downstream of the printing nip. This property, the inherent resistance to film splitting, is generally referred to as "tack", and the formulation of printing inks is based on a balance between tack and ink transfer characteristics.

In the present study, an apparatus was designed, constructed and developed to measure accurately the tack of an ink under simulated printing conditions. The apparatus was interfaced through a storage oscilloscope to a personal computer.

This apparatus was used to make tack measurements on two ink formulations at two speeds.

A technique is proposed to use the methods developed in this research to measure tack in an actual printing nip.

RÉSUMÉ

On connait depuis longtemps qu'une propriété d'encre, ayant une importance centrale, est sa capacité de supporter une stress tensile durant la séparation de la plaque imprimante et la surface imprimée avant lieu dans la région succédant le "nip". Cette qualité d'une filme d'encre. sa resistance à fendre. est généralement appellée le tack et la formulation d'une encre doit être baser sur une balance de son tack et de ses charactéristiques de transfert.

Par la presente on convient le dessine. la fabrication et le dévelopement d'un appareil pour la mesure précise . du tack pour une encre sous les conditions simulant l'imprimerie. Cet appareil formait un systéme intégrant une oscilloscope équippée de mise et un ordinateur personnel.

L'appareil fut utilisé pour la mesure du tack sur deux formations d'encre à deux vitesses.

Il est proposé que ces même méthodes soient utiliser pour la mesure du tack pour de l'encre directement sur un imprimeur.

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Chapter 1

INTRODUCTION

Printing is the transfer of an inked image to a substrate such as paper. The way in which the printing press conditions, and ink and paper properties interact to affect the transfer of ink to paper largely determines the quality of a printed image. This in turn depends on many factors, especially the behaviour of printing ink in the printing nip, where the ink carrying plate is pressed against the paper. An important property of ink, which is related to the resistance offered by an ink film to splitting at the exit of the printing nip, is usually referred to as "tack". Tack forces are not well defined and cannot be properly measured using existing instrumentation.

1.1 Objectives

The primary objective of the research was to develop a technique to evaluate the tendency of inks to support tensile stresses during film splitting. It was hoped that this technique could also be used to measure the tack force generated in an actual printing nip during ink film splitting.

Chapter 2

BACKGROUND AND LITERATURE REVIEW

2.1 Ink Transfer In The Printing Process

Printing is the transfer of an inked image to a substrate such as paper. The commercial printing industry embraces a wide variety of processes for putting ink on paper. Ink formulations, printing forms, and printing pressures differ considerably in these processes, but the ink is invariably transferred from the printing plate to paper in a printing nip, which is where the ink carrying plate is pressed against the paper.

For convenience in describing the mechanism of the printing process, it is divided into four distinct operations.

1. Fountain Feeding: The spreading of an ink film on a roller by a duct and a flexible steel blade.

2. Distribution: The breaking down of any structure present in the ink by a roller train and distribution of a uniform film on the form roller.

3. Transfer: The ink is transferred from the plate or rubber blanket to the paper and the printed sheet is withdrawn from the plate or blanket.

4. Penetration: The drainage of the vehicle into the pores of the paper.

The way in which the printing press conditions and ink and paper properties interact to affect the transfer of ink to paper largely determines the quality of a printed image. Thus the transfer step, in which the ink first contacts the paper, is the most important from a fluid mechanics as well as a process point of view. In the transfer step the ink is transferred from the plate or rubber blanket to the paper and, finally, the printed sheet is withdrawn from the plate or blanket. In the transfer step the ink undergoes a strong compression followed by a weaker tension (1).

The transfer process consists of hydraulic impression followed by film splitting. At full commercial printing speeds, paper passes through the printing nip in approximately one millisecond (2). Fetsko et al (3, 4) have proposed a hypothesis for the events occuring in the nip region. The hypothetical pressure and velocity profiles in the printing nip (5) are shown in Fig. 2.1. The important points of the hypothesis are as follows.

A. In the contact zone

1. Pressure drop; serves as a pump to force ink toward the nip exit.

2. Shear rate variation; from zero to 30,000 reciprocal seconds to zero.

3. Ink interaction with paper surface essential to anchor ink film.

B. In the separation zone; stress buildup relieved by

1. Cavitation (internal vacuum).

2. Cavity growth.

3. Filament rupture.

It should be noted that a region of low or zero shear rate is encountered at the point of maximum pressure. The pressure then drops across the nip. The shear rate, which is greatest where the pressure is falling the fastest, may reach the order of magnitude of 30,000 reciprocal seconds (4).

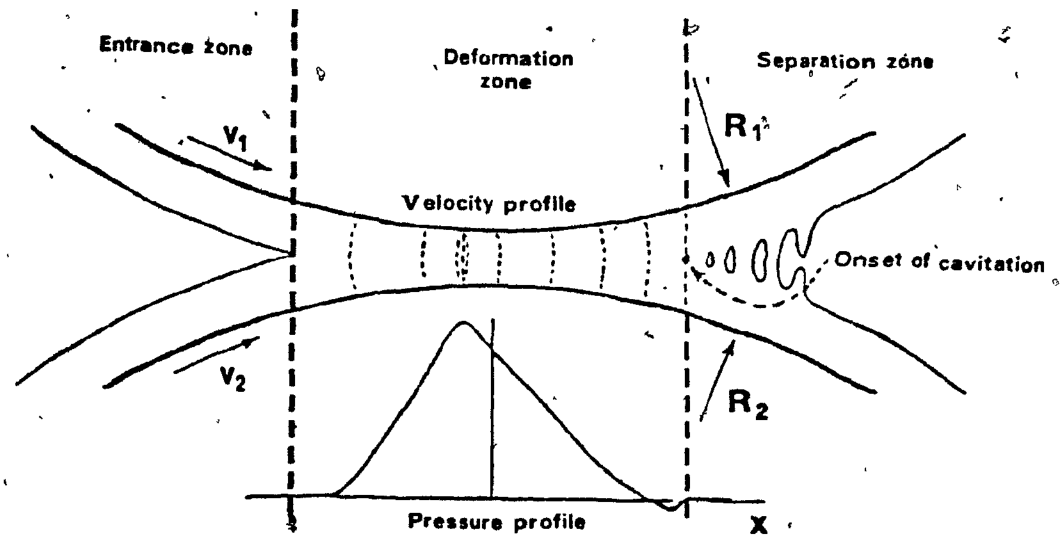


Figure 2.1 Velocity and pressure profiles in the printing nip (hypothetical).

The film pressure reaches a minimum at the end of the nip. Preliminary experiments indicate that this minimum is about one atmosphere vacuum (4). A second plane of zero shear rate is encountered here. At the exit side of the nip, the plate and substrate begin to separate, and the ink film no longer fills the gap between the cylinder and the plate. Tension is created within the film, and cavities form if the cohesive strength of the fluid is exceeded by the adhesive strength of the bond between the fluid and the solid surface. The point of greatest tension is nearly halfway between the surfaces, and cavity initiation is probably greatest in the centre of the film (6).

Filamentation of the ink film occurs as the result of the expansion of cavities in response to the tensile stresses that occur beyond the centre of the printing nip (see Figs. 2.2 & 2.3). These filaments elongate, becoming thinner, and finally break. If the filaments break at two places, a droplet is formed and misting occurs. The formation of cavities and their expansion have been clearly observed in high speed photographic studies carried out by Sjodahl (7), Banks and Mill (8), and by Thompson and Young (9). It is believed that the growth of the cavities controls not only the level at which the filaments break but also their final size. The hypothesis is that the level of split occurs where the bubbles are most numerous and that the

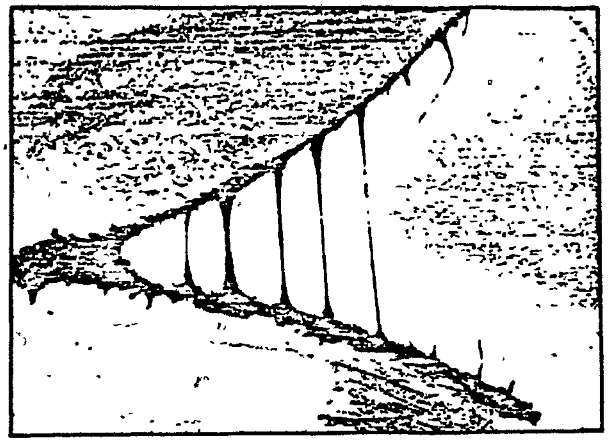


Figure 2.2 Ink filamentation (x 4.3 magnification).

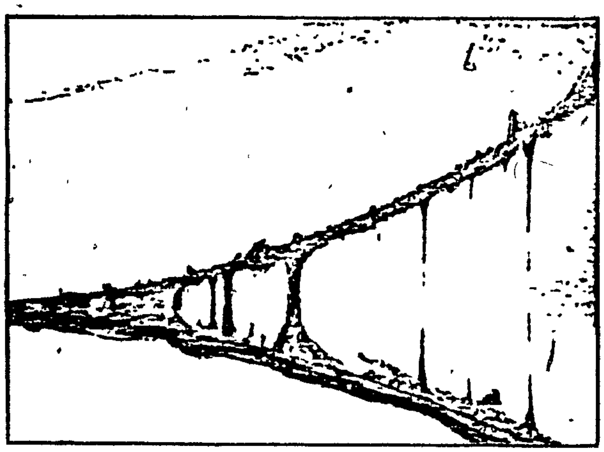


Figure 2.3 Ink filamentation (x 4.3 magnification).

cross-sectional area of the filaments depends on the size of the bubbles at the rupture point (4).

2.2 Ink Film Splitting And Tack Force

It has long been recognized that an ink property of central importance, related to its inherent resistance to film splitting, is its ability to support tensile stresses as the printing plate and the printed surface separate downstream of the nip. This property is generally referred to as "tack", and the formulation of printing inks is based on a balance between tack and ink transfer characteristics.

2.3 Tack And Printing Defects

High tack often accompanies the addition of polymer to improve ink transfer from one roll to the next in the printing press and to prevent undue uptake of fountain solution in lithographic printing. Excessive tack is undesireable, because the tack force is transmitted to the paper surface on the outgoing side of the printing nip and can result in the removal of loosely bound fibers (linting), or in 'picking' of the paper's surface coating or fibers. Lint or picked material accumulates on the printing plate blanket and plate causing a deterioration in image quality (2). This problem is the most serious drawback of the lithographic printing process, a process that otherwise results in sharp, high contrast, high resolution images.

The ability of a printed ink film to accept properly a subsequent ink film application is called 'trapping'. The control of trapping is necessary in process printing where inks of different colors are printed successively, one on top of the other. The second down ink must be trapped by the first down, otherwise it will not print. Hence, in a four color printing process, the first down ink must have the highest tack; the second down a lesser tack; the third down, still less; and so forth. When the splitting force or tack is greater in the second down or succeeding ink film, 'back trapping', i.e. splitting in the ink film previously printed, occurs, and ink transfers back from paper to plate or blanket (3, 10).

2.4 Origins Of Tack Force

The origins of tack force during the splitting of ink films have been open to considerable speculation. Two important factors in the generation of tack force in a printing nip are believed to be cavitation and ink rheology.

2.4.1 Cavitation and tack force

The mechanisms by which a liquid can sustain a negative normal stress are cohesion of adjacent molecules and adhesion of the liquid to a solid boundary. When the applied tension exceeds either the cohesive or the adhesive strength, rupture will occur. As for a solid, the theoretical strength is unlikely to be exceeded in practice. In solids, the strength is limited by the propagation of cracks, while in a liquid, resistance to extension is limited by cavitation.

Film splitting in a roll nip at low speed can be described by a simple hydrodynamic model. The resulting differential equation has been solved for a rigid nip using several alternative boundary conditions, for the case of Newtonian liquids (6, 8, 11, 12), power law liquids (13), and Maxwell liquids (14, 15, 16). The case of deformable roller nips is more complex, demanding simultaneous solution of the equations for roller deformation, and has been studied less extensively (17, 18).

A hydrodynamic analysis of the related problem of splitting in parallel plate geometry has been carried out (19). The results of this analysis indicate that the effect of viscoelasticity on the force, which arises when the plates are separated and the sample splits, is the same as in the roller geometry.

Flow in a nip is amenable to a straightforward hydrodynamic analysis only over a limited distance into the middle of the nip (12). Cavitation at the exit side produces a complex flow field, and elongation and breaking of the filaments formed by cavitation complicate the picture. The same considerations apply to parallel plates (20).

Whether tension in a splitting film of a printing ink reaches a maximum just prior to cavitation or is at its highest at the point of rupture of the filaments is a matter of some controversy. Banks and Mill (19) and Strasburger (20) suggest the former is the case, which suggests that viscous properties are instrumental in determining tack. Bickerman (21) has proposed that only viscous forces are involved in the peeling of a flexible substrate from a plane surface in contact with a Newtonian liquid. On the other hand, if the tension is at its highest at the rupture of the filaments, viscoelastic properties are crucial (22). The high speed photographic studies on film splitting in nips carried out by Erb and Hansen (22), Sjodahl (7), and Thompson and Young (9), have led to different conclusions regarding the relative importance of viscous and viscoelastic ink behaviour. These studies also revealed that surface tension may also be important.

It has been suggested that of the two phases of cavitation, cavity formation and cavity expansion, the former is related to the product of ink viscosity and the velocity of separation of the two roller surfaces above a critical press speed, and attempts have been made to relate this viscosity-velocity product (VVP) with tack forces (23, 24). However this VVP criterion does not apply readily to fluids of different chemical structure; inks with the same viscosity but differing formulation can vary enormously in tack. Truman and Hudson (25) have indicated that the stresses involved in film splitting are not only a function of VVP, but are strongly dependent on the surface properties of the substrate.

Cavitation commences when the cohesion of the ink is overcome locally, so that points of nucleation are helpful in cavity formation. In fact, Miller and Myers (23) found by a high speed photographic study of film splitting in a low pressure chamber that while the film splitting pattern was unchanged down to 0.1 atm pressure, the work of separation increased due to the loss of the contribution of air expansion within the film.

Cavity formation is catalysed by surfaces; consequently the number of incipient bubbles formed increases with the number of particles in the ink, probably because air pockets trapped on particle surfaces act as cavitation nuclei, and this reduces the ink filament size (4, 24). In general, suspensions cavitate more readily than their vehicle fluids, and large pigment particles initiate cavitation sooner, thus causing tack forces to be smaller. On the other hand, smaller particles that cause cavitation later will lead to finer filaments, thereby improving print quality by improving the uniformity of ink transfer (2). Interfacial tension between pigment and vehicle may also play a role (23).

The second phase of cavitation is the expansion of cavities. It has been hypothesized that the greatest expansion takes place where there is the least resistance, which is in areas of reduced viscosity. With highly thixotropic inks, due to the higher shear rates exerted closer to the paper, the viscosity is lower in this region. This causes the film to split closer to the paper than to the plate, resulting in a transfer of less than 50%. This behaviour has been observed with heavier vehicles, finer particle sizes, and higher pigment loadings (4).

In the expansion of cavities, the increase in total surface energy due to the creation of new surface is expected to make a contribution to the tack force. This means that in addition to viscosity, surface tension also resists the expansion of cavities. However, in an analysis of cavity expansion within a polyisobutene oil, Hoffman and Myers (26) found that surface tension contributed only 7% and viscosity 93% of the work of separation of the oil film.

In an extensive literature survey on cavitation in bearings, Dyer and Reason (27) found a consensus that a liquid's tensile strength is sensitive to such factors as gas content, viscosity, particle content, and the surface finish at the liquid-bearing material interface. They mentioned the possibility of serious damage to the bearing surface, particularly a tendency to 'pluck out' pieces of material from the Babbitt matrix, as a result of tensile stresses in the lubricant.

2.4.2 Ink rheology and tack force

It is clear from the complexity of the rheology of inks that the simple tests now used in the printing and ink industries, such as viscosity measured at a single shear rate, are inadequate for predicting the behaviour of an ink in a printing situation. In addition, we lack a proper understanding of the fundamental phenomena occuring in the printing nip. Our lack of understanding is apparent in the methods used to measure ink tack and paper surface strength using "tacky" liquids.

Viscosity is not the only factor governing the tack of a liquid. This was demonstrated by comparing polyisobutene oil with a silicone oil of equal or higher viscosity. Compared to polyisobutene oil, silicone oil has virtually no tack, as indicated by its inability to pick the surface of paper at even the highest speeds attainable in the IGT tester (28). The viscosity - tack relationship is tenuous and breaks down when vehicle chemistry or ink 'shortness' changes (29). Shortness is defined as the ratio of yield value to plastic viscosity. Yield value is commonly interpreted to be the intercept on the shear stress axis of the extrapolated linear portion of the shear stress versus shear rate curve.

As mentioned previously, at very slow rates of film splitting, a simple hydrodynamic model can be used to predict the separation force. The viscosity-velocity product (VVP) gives a reasonable indication of the separation force in this case. However, it should be born in mind that even pure polymeric liquids, such as the polyisobutene used by the paper industry to measure the surface strength or picking resistance of paper, is non-Newtonian at high shear rates. It is difficult to select the viscosity value relevant to print simulation tests (2). More importantly, the VVP does not predict the separation force at the high rates of separation encountered in printing due to cavitation effects and complex flow behaviour in the ink filaments.

It has been hypothesized that it is the rheological properties of an ink that govern its tackiness. According to work done by Oittinen (30) particle-particle and particle-vehicle interactions are changed by the addition of polymer to ink. On the other hand, both lithographic ink and concentrated solutions of tackifying resins are viscoelastic and cause picking. At the same time, tacky polyisobutene oils are inelastic (28). However, it has been proposed by Aspler (31) that the change in tack that accompanies polymer addition to ink may have its origins in the chemical structure of the polymer, particularly its backbone flexibility. Preliminary NMR studies support this hypothesis.

Temperature effects must also be considered, since an increase in temperature results in a lowering of the viscosity and tack of ink and surface strength test liquids (32, 34).

It can be seen that the tack forces generated during the splitting of ink films are not well defined and are caused by several competing and interrelated phenomena. Tack cannot be easily measured by the use of instrumentation now available. It can best be described as the resistance or tensile force involved in the splitting of an ink film at the exit of a printing nip.

2.5 Tack Force Measurement

Because of the significance of tack in practice, it is important to be able to predict reliably the splitting behaviour of a printing ink by means of a laboratory test.

2.5.1 Parallel plate geometry

The oldest technique for measuring tack depends on the printer's finger, which he uses to put a dab of ink onto the paper and then discerns the resistance to snapping the finger away from the paper. In spite of its primitive and subjective nature, this method is still widely used.

The mechanical tack finger of Green (34) was an attempt to quantify the craftsman's test. This device differs from practice in that the separation involves rather slow motion of the surfaces normal to each other, and in an actual printing process air is mixed into the ink by a roller.

Much work has been done to develop tack measuring systems based on parallel plate geometry, as indicated in Table 2.1. The parallel plate tackmeters vary in the film thickness range used, the form of the motion that separates the plates, and the force measuring system. A number of plate tackmeter designs, together with some specifications, are listed in Table 2.1. Fig. 2.4 shows the design of a parallel plate tackmeter (35).

An advantage of a parallel plate tackmeter over a roller tackmeter is that splitting forces can be registered as a function of time. However, in the parallel plate geometry the speed and other test conditions do not simulate well printing nip conditions, with the result that parallel plate tackmeters cannot be used to predict ink behaviour in a printing press.

Table 2.1 Parallel Plane Tackmeters

Tackmeter identity	Gap in microns	Plate separation/ Form of motion	Force measuring system
Green (34), 1941	100	Constant weight	Manual measurement of time
Strassburger (20), 1956	50	Constant velocity, 0.06 - 6 cm/s	Piezoelectric crystal and oscilloscope
Erb & Hansen (22), 1960	1000	Constant velocity, 0.5 cm/s after start	Movement of bottom plate measured from high speed photos; force calculated using Newton's 2nd law of motion
Curado, 1963	100	Sinus wave oscillation; velocity of top plate, 0 - 18 cm/s	Strain gage and oscilloscope
GATF, 1963		Rebound by means of a spring after a hammer has hit an anvil	Strain gage and oscilloscope
NPIRI, 1969	5 - 15	Manual separation	Push/pull gage and read-out dial
Kelha et al. (35), 1973	3 - 50	Spring loaded: top plate moves at constant accelaration 50 m/sq.s	Piezoelectric crystal, oscilloscope, electronic memory and chart recorder

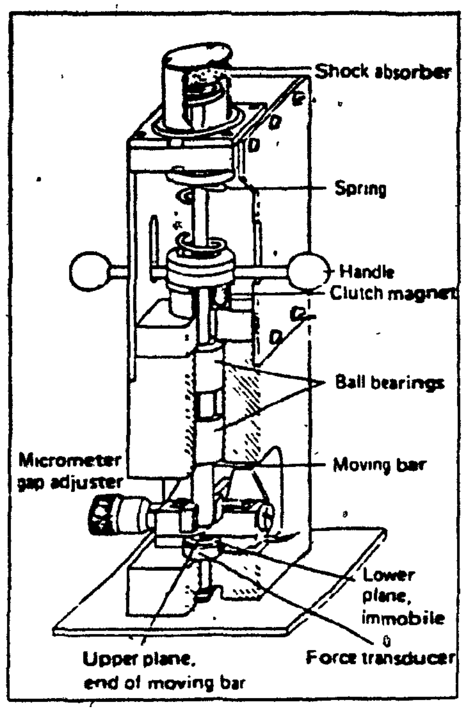


Figure 2.4 Parallel-plane tackmeter (Kelha et al. (35)).

2.5.2 Roller geometry

Reed (36), designed a tack measuring instrument called the 'Inkometer' using roller geometry. This instrument measures the torque exerted on one roll of a simple distributing system as the ink is being worked. The torque is transmitted through a linkage to a balance arm above the torque roller, on which readings are taken as depicted in Fig. 2.5. The degree of displacement of the upper cylinder is proportional to the 'inkometer number' of the liquid applied to the cylinder surfaces.

The inkometer was originally designed in an attempt to simulate the printing press situation by scaling down the printing roller nip. Many researchers have attempted to correlate the inkometer number of an ink with tack. It is now recognized that such efforts are futile. Inkometers fail because they do not measure normal force but rather a complex combination of viscous, tack and elastomeric effects (18, 37). Furthermore, the inkometer does not correctly simulate a printing press, partly because the optimum film thickness for measurement is several times greater than that found on a press, and partly because equilibrium readings are very difficult to obtain (38). Superimposed upon these drawbacks is the fact that the torque roller is made of a rubber composition and no such composition has been

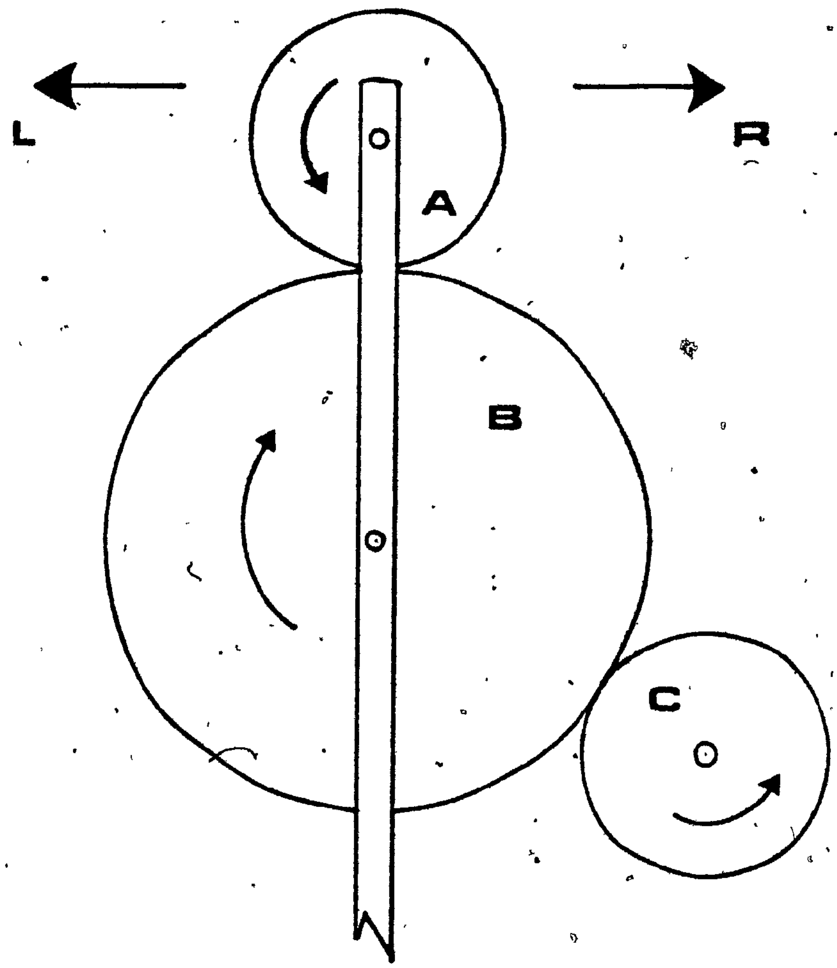


Figure 2.5 The principle of operation of the Inkometer,
A: The movement of this cylinder is proportional to the Inkometer number. If the cylinder is displaced towards the left the Inkometer number decreases; while if displaced towards the right, the Inkometer number increases.
B: Motor driven cylinder.
C: Cylinder used for application of even film as it possesses reciprocating motion.

developed that will ensure the stability of the physical characteristics of such rollers (1).

In the Patra tack meter (39) the Inkometer is attached to the distribution system of a press. The Tack-o-scope (40) is another tack measuring device operating on the basis of roller geometry and is very similar to the Inkometer.

A major disadvantage of all of these rotational tackmeters is not being able to measure the normal force. Furthermore, the actual nip conditions cannot be reproduced because no ink is transferred to paper, as splitting of ink takes place between two rollers. Furthermore, splitting forces cannot be profiled through the printing nip.

2.5.3 Energy as a measure of tack

Voet and Geffken (41) proposed that tack could be determined by measuring the decrease in kinetic energy suffered by a rolling cylinder as it passes over an inked surface mounted on an inclined plane of U - shaped tracks (see Fig. 2.6). This work culminated in the concept of tack as an energy density, with the energy requirement dependent upon the volume of ink transferred from the plate to the roller. Recently, Watanabe and Amari (42) have attempted to

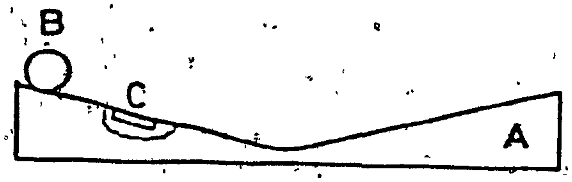


Figure 2.6 Schematic diagram of Voet's rolling cylinder tackmeter for measuring tack of printing ink.
A: U-shaped tracks,
B: Cylinder,
C: Sample holder.

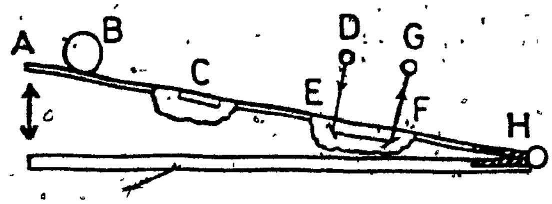


Figure 2.7 Schematic diagram of modified rolling cylinder tackmeter.
A: Straight tracks, B: Cylinder,
C: Sample holder, D: Light source,
E,F: Mirror, G: Photo-sensor,
H: Hinge.

overcome two disadvantages of Voet's apparatus. They controlled the roller speed over a wide range and employed a photoelectric technique to measure the kinetic energy of the roller more precisely (see Fig. 2.7).

2.5.4 Measurement of tensile stresses in bearings

In an experimental study on a steadily loaded bearing, Dyer and Reason (27) have observed tensile stresses of 740 KN/m^2 (107.3 psi.) in an oil film. To measure these tensile stresses, they used a strain gauge diaphragm pressure transducer. The lubricant film thickness was measured simultaneously by an inductance proximity transducer. Both were mounted in the rotating shaft. This study indicated a dependence of the tensile stress on the rate of divergence of the bearing surfaces.

Later, Brown and Hamilton (43) observed larger negative pressures (up to -780 KN/m^2 or -113.1 psi.) in the oil film lubricating a piston ring. The instrumentation they used consisted of a pair of capacitance gauges, for measuring the oil film thickness, mounted on either side of a piezoelectric pressure gauge. One difference between the observations of this study and of the previous one is the magnitude of the negative pressures. In the present study, the whole of the outlet region is under negative pressure, whereas in the former study only a small negative pressure was found relative to the magnitude of the positive pressure.

Recently, in an experimental study of the pressure distribution in a super laminar journal bearing, Roberts and Hinton (44) recorded negative pressures down to -17.4 psi. In this study miniature pressure transducers operating on the piezoelectric strain gauge principle were used. Furthermore, in order to study the oil film pressures in squeeze film dampers, Holmes (45) used a miniature piezoresistive pressure transducer of type EPK-125 made by Entran.

Chapter 3

DESIGN AND DEVELOPMENT OF THE TECHNIQUE

The behaviour of ink in a printing nip is very complex. Therefore, to evaluate an ink for use in the printing process it is necessary to simulate in some sense the conditions existing in an actual printing nip. A number of important nip and flow variables are listed in Appendix A along with order of magnitude values. First, the geometry of the printing press should be properly scaled. Secondly, there should be some way to control the splitting speed, as ink behaviour depends on strain rate and time scale. By a similar argument, the normal force and film thickness should be accurately measured by some means.

3.1 The Hypothesis

As a working hypothesis, it was assumed that 'tack forces' are the tensile forces supported by an ink film just before film splitting occurs. For this reason, in the research a state-of-the-art microforce transducer was mounted on one face of a simulated printing nip in order to record accurately the tack force under printing conditions.

3.2 Design Of The Technique

At the present time, only two kinds of geometry are used in printing processes: cylinder-plane geometry (as in flat-bed letterpress printing) and two roller geometry (as in lithographic printing). For this research, the cylinder-plane geometry was chosen for two reasons. First, it is much easier to mount a pressure transducer in a flat surface than in a curved surface. The second reason was that the two roller geometry requires some mechanical means to drive the rollers at the same speed and to control the gap between the rollers, whereas with cylinder-plane geometry only the cylinder or the plane need move with respect to the other, which allows a much simpler mechanism.

As a first attempt to measure tack force and predict the behaviour of ink in a printing nip, the instrument sketched in Fig. 3.1 was constructed. The main parts of the apparatus are a steel plane (430 x 150 mm), inclined at an angle of 17.5° to the horizontal and a cylinder, the latter consisting of a jacket with steelends and an inner core of lead. The lead core is mounted eccentrically on a shaft on which the outer jacket was coupled by means of ball bearings. The jacket can thus rotate independently of the inner lead core and in this way rotational inertia and slip are minimized. The diameter of the cylinder is 147mm, while its weight can be varied by removing a portion of its lead inner core.

A miniature pressure transducer of the type EPX5-10W-100 made by Entran Devices Inc. was mounted in the lower plate, and was used to measure the tensile forces generated on the outgoing side of nip during the splitting of an ink film. The maximum tensile stress was assumed to be a measure of ink tack. The transducer made use of a semiconductor strain gauge bonded directly to a stainless steel diaphragm and had a working pressure range of 0-100 psig. It was mounted flush with the plate surface and 138 mm from the lower end. The mounting arrangement is shown in Fig. 3.2.

At a nearby location on the inclined plate, at the same distance from the end as the pressure transducer, a

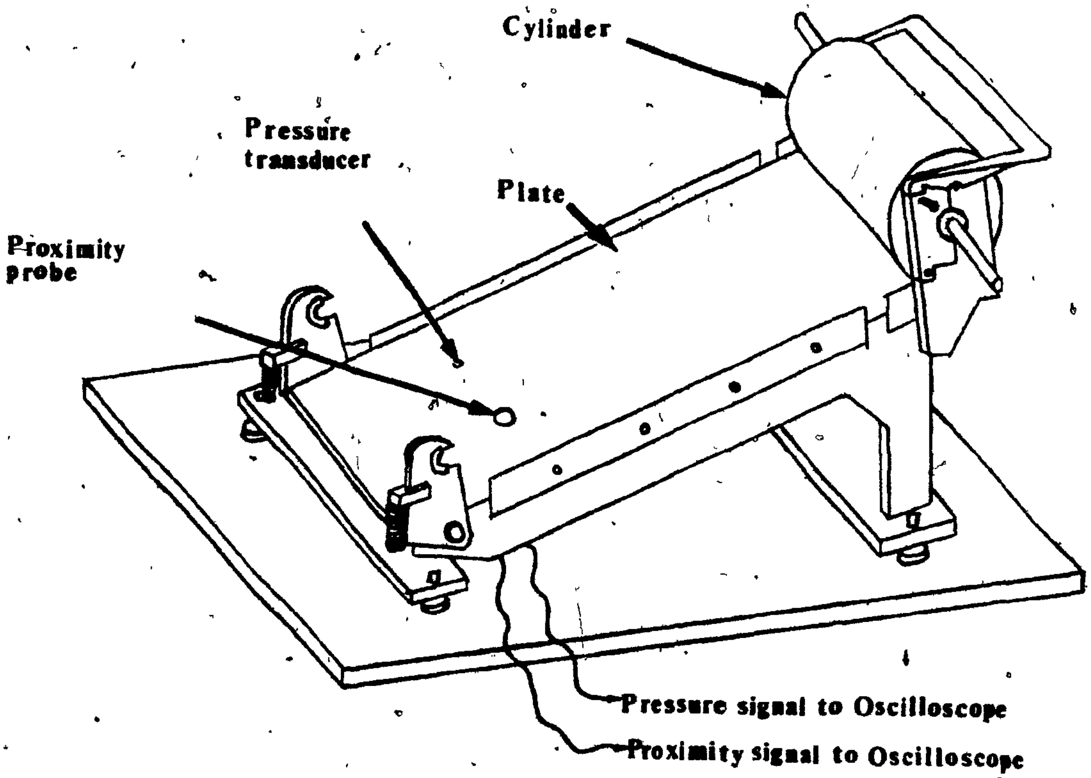


Figure 3.1 Test apparatus for tack force measurement.

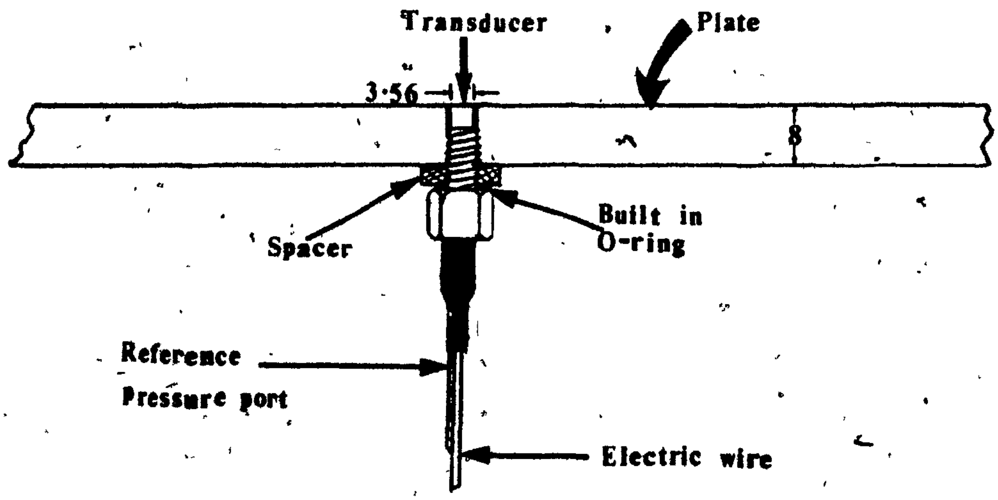


Figure 3.2 Mounting arrangement for the Entran pressure transducer. (All dimensions are in mm.)

proximity probe is mounted to monitor the film thickness as the roller passes over. Fig. 3.3 shows the mounting of the proximity probe. The proximitor system uses an eddy current technique to detect the gap between the probe tip and a metal surface (in this case the cylinder surface) and converts this distance to a proportional negative dc voltage. The system measures both static (fixed) and dynamic (changing) distances. The proximitor calibration curve and calibration procedure is given in Appendix B. The following equation, used to calculate the angular velocity of the cylinder from film thickness versus time curve, is derived in Appendix C.

$$F(t) = F' + R(1-\cos\Omega t)$$

Hence angular speed $\Omega = 1/t \cos^{-1}(1- (F(t)-F')/R)$

And peripheral velocity $v = \Omega R$

where,

- R = Radius of the cylinder
- t = Time (t=0 at the point of minimum gap)
- $F(t)$ = Gap at time t
- F' = Minimum gap between the cylinder and the plate

To remain in the linear operating range of the proximity probe, the probe tip should be fixed at some distance from the plate surface (more than 225 microns) while installing it. This can be done by measuring the

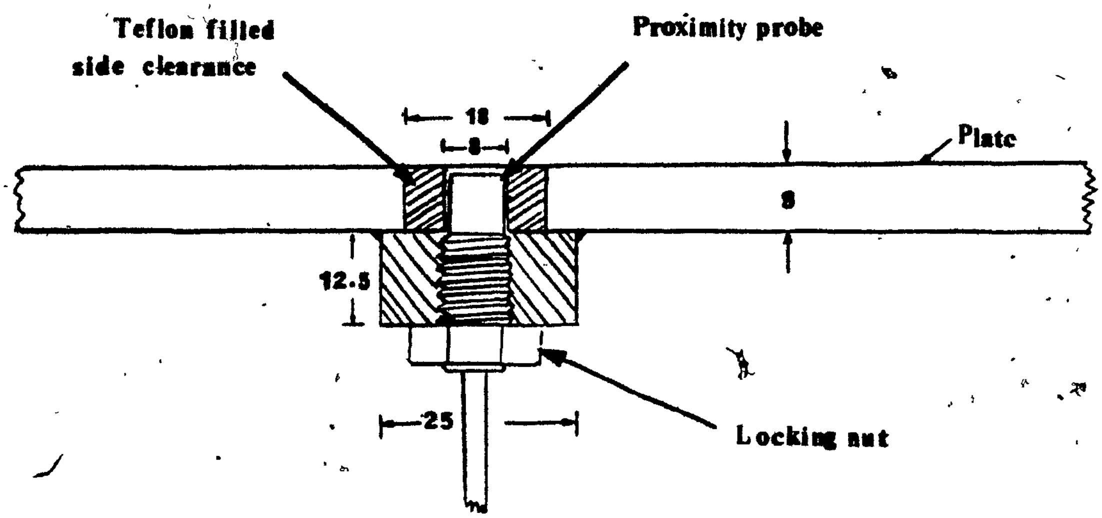


Figure 3.3 Mounting arrangement for the proximity probe.
(All dimensions are in mm.)

proximity output with an accurate multimeter and reading the gap from the calibration curve of the proximity probe. This reference gap is used in calculating the nip.

To measure the reference gap accurately, a run was done without any liquid on the plate while setting the reference gap variable in the computer program equal to zero and running the program. The film thickness calculated by the computer is the reference gap for a given probe installation. Again this reference gap value is stored as the reference gap variable of the program and the program can then be used for experiments until the proximity probe installation is altered.

3.3 Preliminary Experiments

The output signals from the pressure transducer and the proximity probe were recorded on a storage oscilloscope equipped with a Polaroid camera.

Initially, the power supply to the apparatus is turned on, a small amount of ink is placed on the plate and distributed with a small rubber roller. The cylinder is fastened in the clamp at the upper end of the plate. The oscilloscope is set to store the pressure and proximity output signals. When the lever on the clamp is pressed down the cylinder rolls down the plate over the pressure transducer and the proximity probe and hits the lower stoppers. The pressure and proximity signals are stored on the oscilloscope and photographed with the Polaroid camera.

The maximum working pressure of 100 psig was an estimate based on the results of lubrication experiments. In any event, it was found to be highly inaccurate, and as a result the transducer was damaged due to excess pressure (235 psi), after only two experiments, on the first day of experiments. A second transducer of the same type (EPX5-10W-500G) but with a working pressure range of 0 to 500 psig, was then ordered.

3.4 Modification Of The Technique

On calculating the speed of the cylinder from the results of the first experiments, it was found that the speed was very low compared to those typical of actual printing presses. It was thus considered necessary to increase the speed of the cylinder by some means. To be able to vary the speed of the cylinder a screw actuating mechanism was provided on the apparatus as shown in Fig.

3.4. The plate was pivoted at its lower end and supported on the screw mechanism so that by turning the shaft the plate angle with the horizontal could be varied from 0 to 60^{O}. The plate angle was measured by means of an air bubble protractor attached to the side of the plate.

The shock experienced by the cylinder stoppers and the lower edge of the plate was quite large, and it was felt this could result in damage to the apparatus. To reduce the shock, by absorbing kinetic energy from the cylinder, an air cylinder was mounted on the underside of the plate. This cylinder was connected to the stoppers by a lever mechanism. To operate the cylinder, compressed air at 10 to 20 psi was required.

When the second Entran pressure transducer was received and mounted on the apparatus, experiments were resumed. The new transducer had a working pressure range of 0 to 500 psi., and as a result, its sensitivity was less than that of the first one. At the same time, the negative pressure peak (tack force), rather than the largest positive peak was of main concern in the research. Hence, it was necessary to amplify the pressure signal to obtain an accurate value for the tack force, but the noise produced by the transducer circuitry was also amplified. This made it difficult to obtain accurate data from the transducer output. Many different kinds of filter circuit were tried but none of

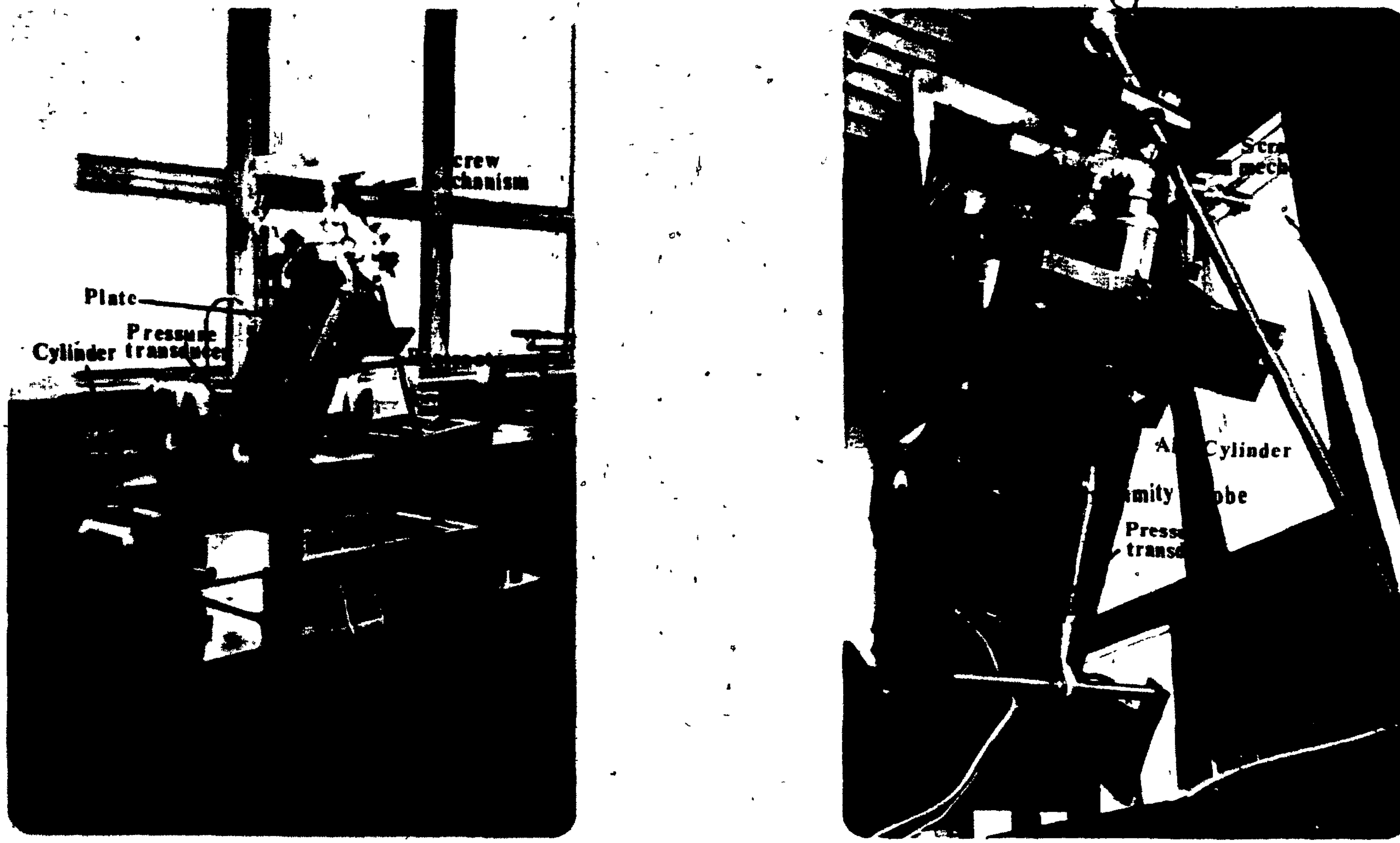


Figure 3.4 Modified apparatus for tack force measurement.

these succeeded in providing a satisfactory signal.

What was needed was a sensitive but robust miniature pressure transducer, and a further search led to a model manufactured by PCB Piezotronics Inc. Piezoelectric devices are noted for their wide pressure range, good frequency response and rigidity. A model 105A13 was ordered. This transducer can also be supplied by the manufacturer with a curved pressure-sensitive surface to facilitate its mounting in a cylindrical surface.

This transducer makes use of a quartz crystal for pressure to charge transduction and has a working pressure range of 0 to 1000 psi. Compared to the Entran transducer (EPX5-10W-500) it has a 50% smaller sensing area, which is better for localized pressure measurements. Furthermore, it has a sensitivity of 4.023 mv/psi, which is 19.626 times higher than that of the Entran transducer (0.205 mv/psi).

The PCB transducer was mounted in the plate at the same horizontal level as the Entran transducer and the proximity probe. Fig. 3.5 shows the locations of the PCB transducer and the proximity probe. The mounting of the PCB transducer is shown in Fig. 3.6. As the Entran transducer did not give useful results, it was removed from the plate. The PCB transducer was used for all subsequent experiments, and the output was found to be very good in quality. Next, an attempt was made to reduce the film thickness to levels

COLOURED PICTURES
Images en couleur

Figure 3.5 Locations of the PCB pressure transducer and the proximity probe.

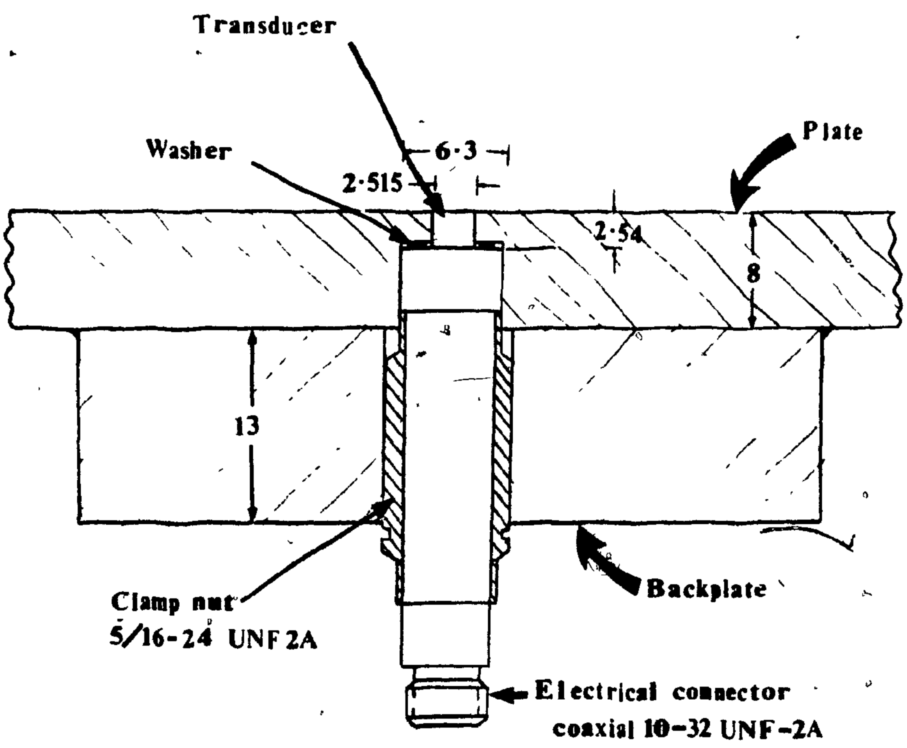


Figure 3.6 Mounting arrangement for the PCB pressure transducer. (All dimensions are in mm.)

closer to those of an actual printing situation. For this purpose the amount of ink on the plate was gradually reduced, and tack readings were taken. On reducing the film thickness below 50 microns, the transducer did not respond at all. The reason for this was probably improper contact between the plate and cylinder. The surfaces of both the plate and the cylinder were examined, and it was found that the plate was lower in the center along all its width, causing the cylinder to touch only at the edges. Similarly, the cylinder was not flat and smooth. A lapping operation was carried out to flatten and smooth both surfaces. As an additional safeguard the outer one inch of the cylinder surface was reduced 2 mm in the diameter on both sides. The tolerance achieved after this surface modification work was less than 10 microns.

Finally, the analog storage scope was replaced by a digital storage oscillocope to store the signal from the apparatus. As this oscilloscope stores data in digital form, interfacing the oscilloscope to a computer was facilitated, and a personal micro-computer (model IBM PC) was interfaced with the oscilloscope. An interfacing board, GPIB-PC2, made by The National Instruments was installed in the computer to interface it with the IEEE 488 interface of the oscilloscope. A program was written to acquire data from the oscilloscope through the interface and to calculate the maximum pressure in the nip, the tack value, the film thickness and the speed, and to plot the waveforms on a dot matrix printer. This program is listed in the Appendix D.

3.5 Final Experimental Setup

The experimental apparatus, including all the features described above, is shown in the Fig. 3.7. The apparatus was placed on a table, on the side of which the electrical circuits for the pressure transducers and proximity probes were fixed. The diagrams of these circuits are shown in the Appendix E. The output signal coming from the pressure transducer is fed to the left amplifier and that from the proximity probe to the right amplifier of the digital storage oscilloscope. The oscilloscope was interfaced to the personal computer with an IEEE-488 interface and cable. The necessary software programs to acquire data and to do calculation and plotting were loaded from floppy disks.

3.6 Final Experimental Procedure

The apparatus, the oscilloscope, and the personal

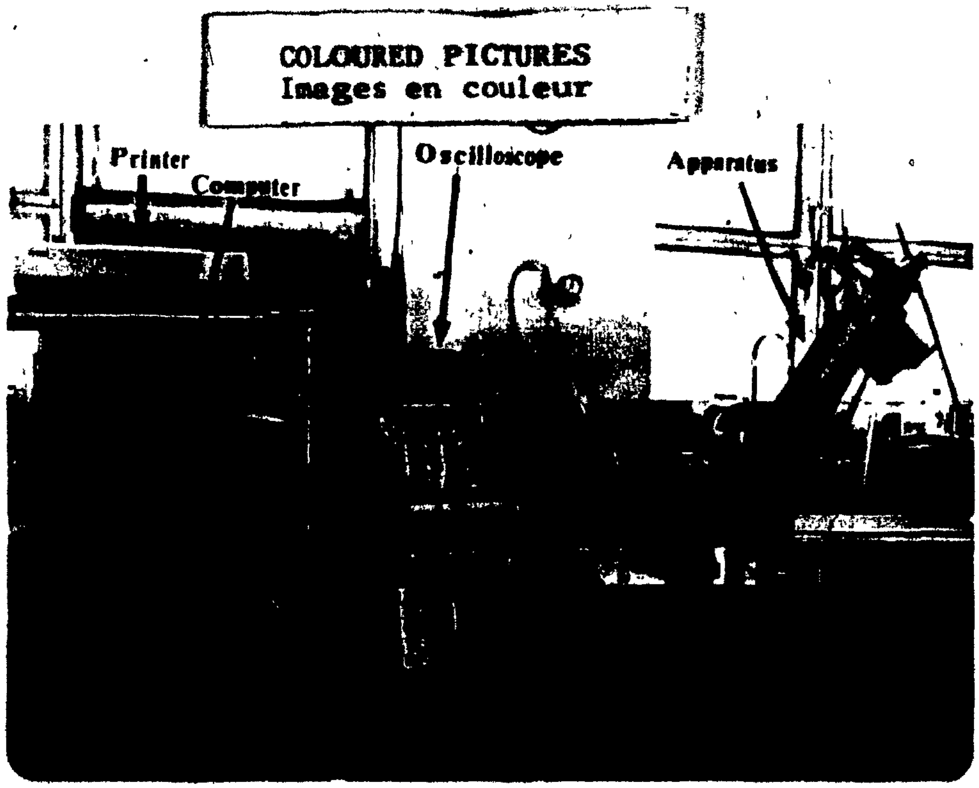


Figure 3.7 Experimental setup.

computer were arranged as described above. The angle of the plate to the horizontal was fixed to the desired value for a particular speed. Pressure of air, supplied to the air cylinder, was set around 15 psi. The power supplies for the oscilloscope, the transducer and the probe were turned on. The power supply to the computer was also turned on after putting the software disks in the proper diskdrives; the GPIB-PC distribution disk is to be placed in drive "a" (the default drive), and the Basic program disk is to be placed in the drive "b". As the PCB quartz transducer is a charge device it takes a few minutes to achieve nearly zero voltage output from the transducer. The proximity probe gives a maximum negative voltage at infinite distance from the target surface; i.e., when the cylinder is far away from it. As the cylinder surface comes near during an experiment the proximity output increases towards zero voltage.

After the programs have been loaded and are ready to run, the plate is inked with the rubber roller (see Fig. 3.8) and then, if required, with the cylinder by rolling it up and down the plate by hand. When a good distribution of ink on the plate is achieved, the cylinder is fixed in the clamp at the upper end of the plate as shown in Fig. 3.9. The controls on the oscilloscope are set to trigger and capture the transducer signals. The cylinder is released from the clamp and rolls down the plate. When it passes over the probes the oscilloscope is triggered and stores in

Figure 3.8 Inking of the plate.

Figure 3.9 Fixed cylinder on top of the plate.

a single sweep the outputs from both probes. The cylinder hits the lower stopper and stops abruptly. The stored signals in the oscilloscope are sent to the computer, and the Basic program is run to do the calculations, print the results and plot the waveforms on the screen.

If the film thickness of the ink on the plate is not in the range required, the plate is inked again. The experiment is repeated for the same angle of the plate but for different film thicknesses for a given ink, to study the effect of film thickness on tack.

Chapter 4

RESULTS AND DISCUSSION

The compositions of the inks used in this research are listed in table 4.1 (5, 28, 46).

Table 4.1 : Compositions Of Inks Used.

Ink No.	Black Base wt. %	Varnish wt. %	Oil wt. %	Asphaltum Pitch wt. %
2	24	33	43	--
18	60	33	3	4

Varnish: 30% Picco 6140-3 Resin.
70% Sunthene 4240 Oil.

Black Base: 33.3% Elftex 8 Carbon Black.
66.6% Sunthene 4240 Oil.

A plot of cylinder speed versus film thickness is shown in Fig. 4.1 for both inks and two different angles of inclination of the plane. It can be seen that the speed of

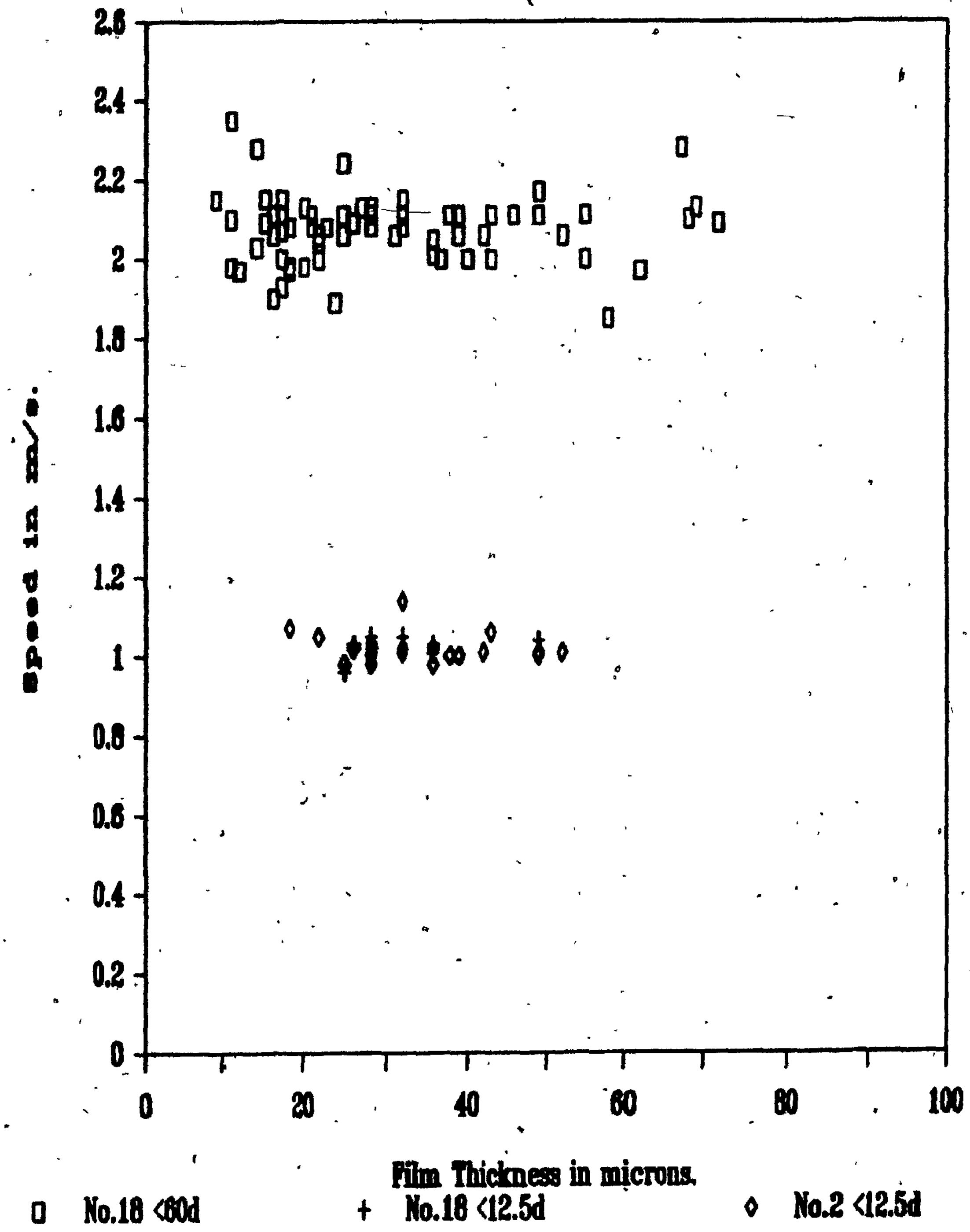


Figure 4.1 Cylinder speed variation for a particular angle of plane.

the cylinder remains almost constant for a given angle of inclination of the plane, irrespective of film thickness or ink composition. Here speed calculations are shown for both inks 18 and 2.

Some typical experimental results are shown in Figs. 4.2 to 4.5. Fig. 4.2 shows the pressure and proximity output versus time for a typical experiment. As we can see from the plot; the pressure output shows two peaks, a positive and a negative. The pressure profile is comparable to that shown in Fig. 2.1. The negative peak value is referred to in this work as the measured tack. The proximity probe output voltage increases from a base negative value towards zero and drops back to the same base level, as the cylinder passes over the proximity probe. The peak value of the proximity probe output for an experiment with the plate inked is compared with the peak value of an experiment without any liquid on the plate to calculate the film thickness. The waveforms are captured by the storage oscilloscope and downloaded to the IBM PC, which calculates the peak values and prints out the results and the waveforms as shown in Fig. 4.3. Another typical experimental result is shown in Fig. 4.4 with the corresponding computer printout shown in Fig. 4.5. It is to be noted that the shape of output waveforms is the same as for the previous experiment shown.

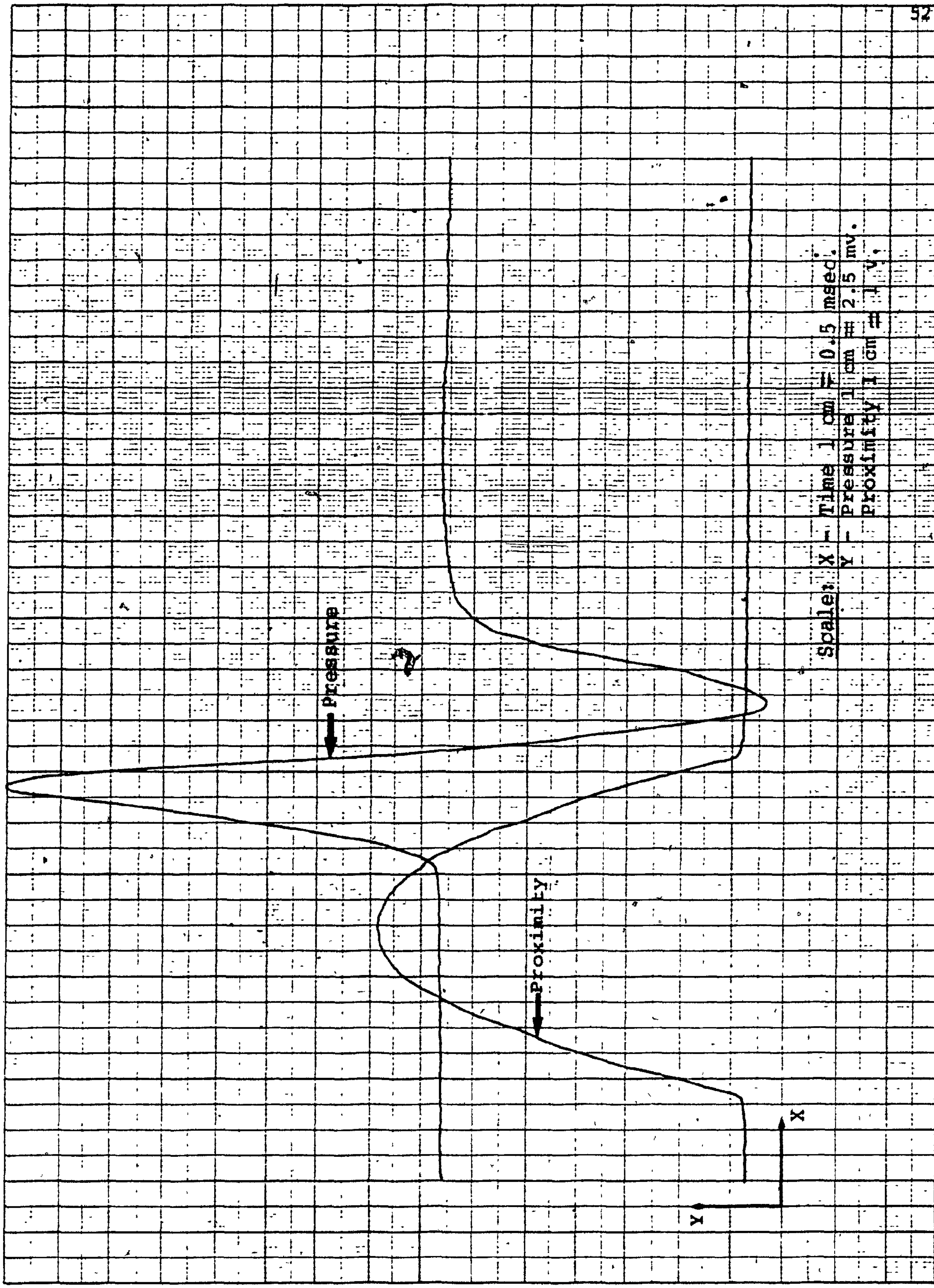


Figure 4.2 Pressure and proximity probe output versus time for a typical experiment.

Ink. no. 2 Angle of plane 60 deg.
Maximum pressure 53.69 psi. Tack 39.40 psi.
Film thickness 59 microns Speed 2.24 m/sec.
Scale: X- Time 1 div = 1 msec. Y- Pressure 1div = 50 mv.
- Proximity 1 div = 2 v.

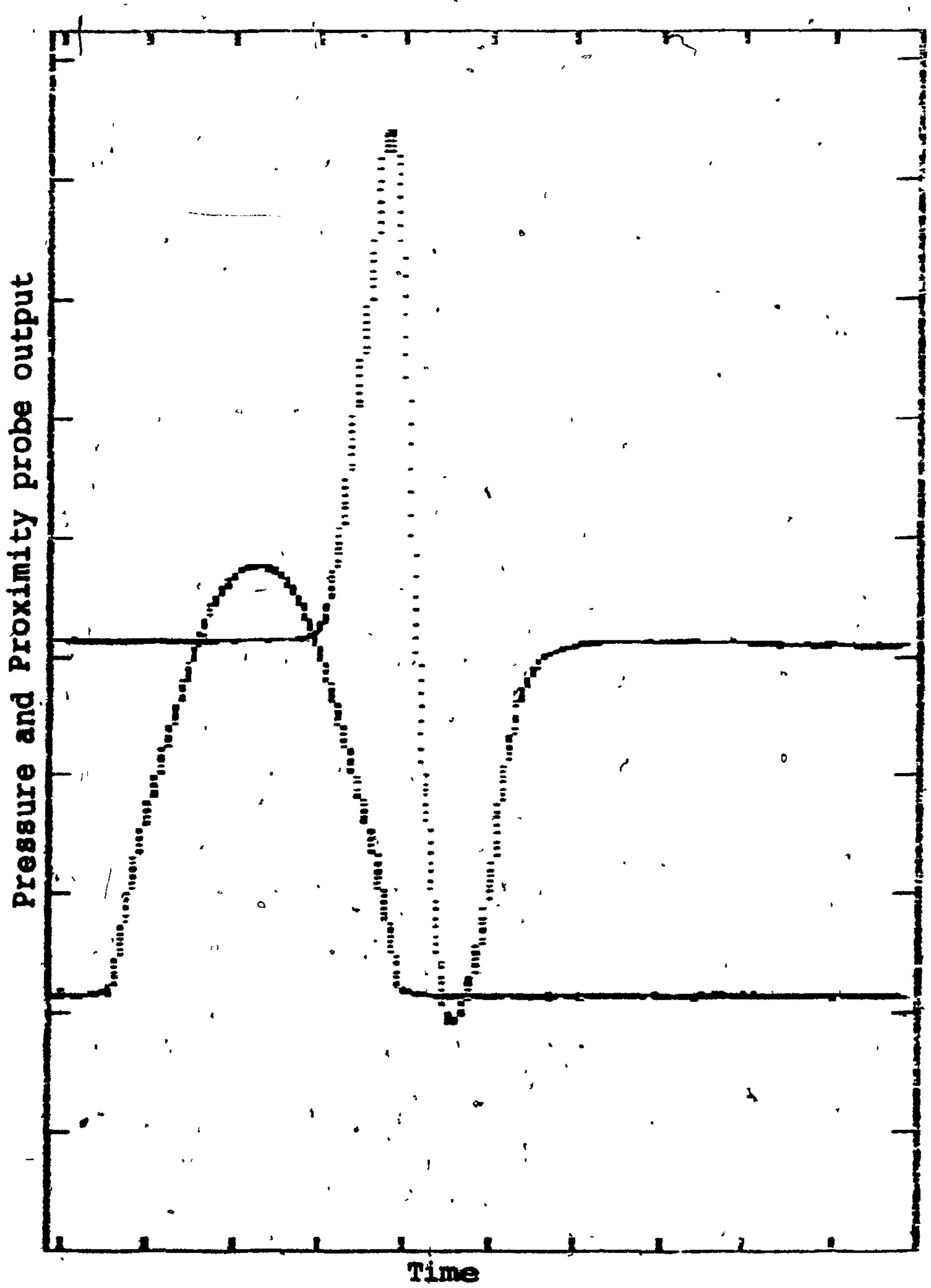


Figure 4.3 Computer printout for the experiment recorded in Figure 4.2.

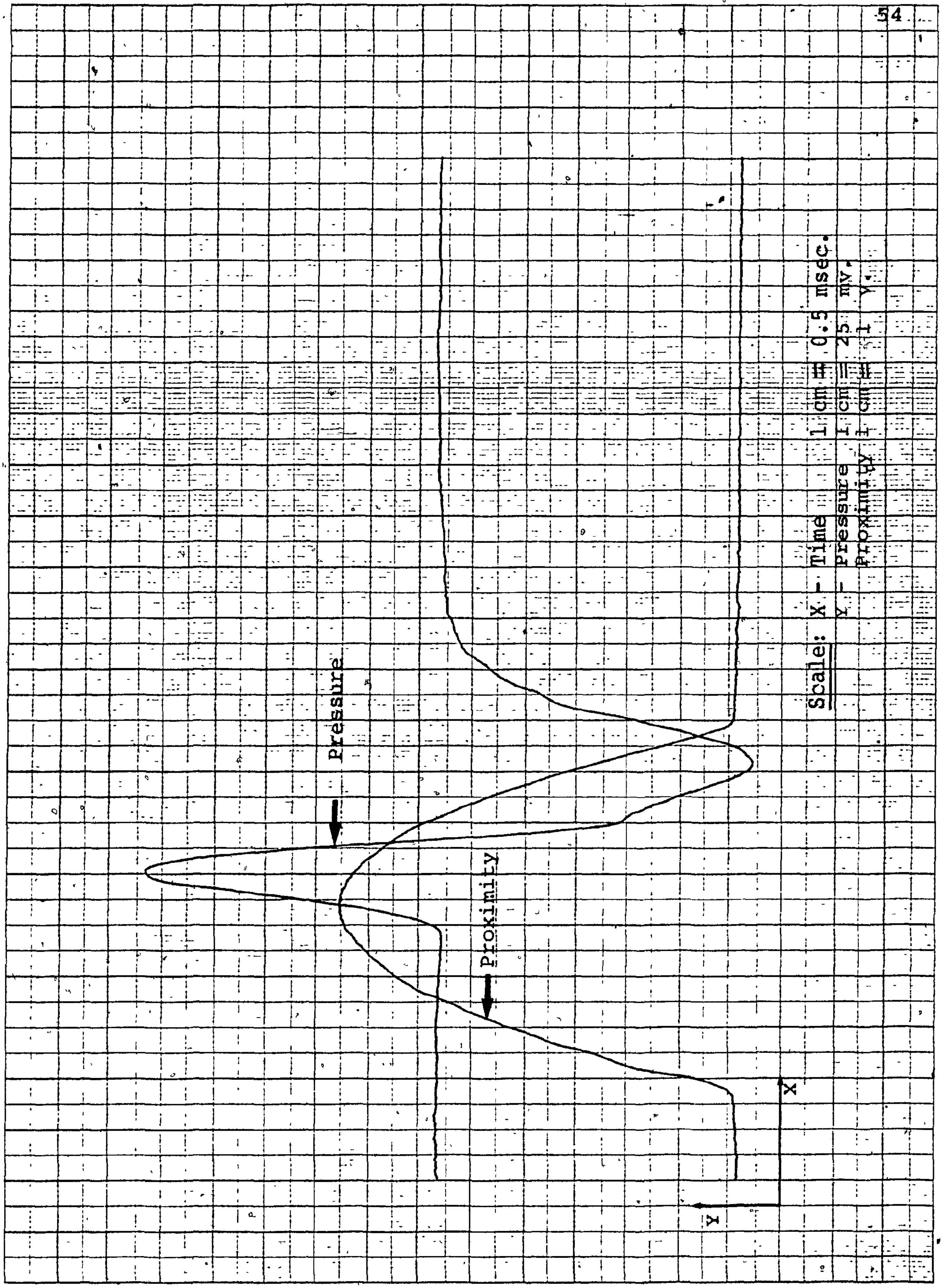


Figure 4.4 Pressure and proximity probe output versus time for a typical experiment.

Ink no. 18 — Angle of plane 60 deg.

Maximum pressure 35.92 psi. — Tack 38.65 psi.

Film thickness 52 microns — Speed 1.88 m/sec.

Scale: X- Time 1 div = 1 msec. — Y- Pressure 1 div = 50 mv.

\- Proximity 1 div = 2 v.

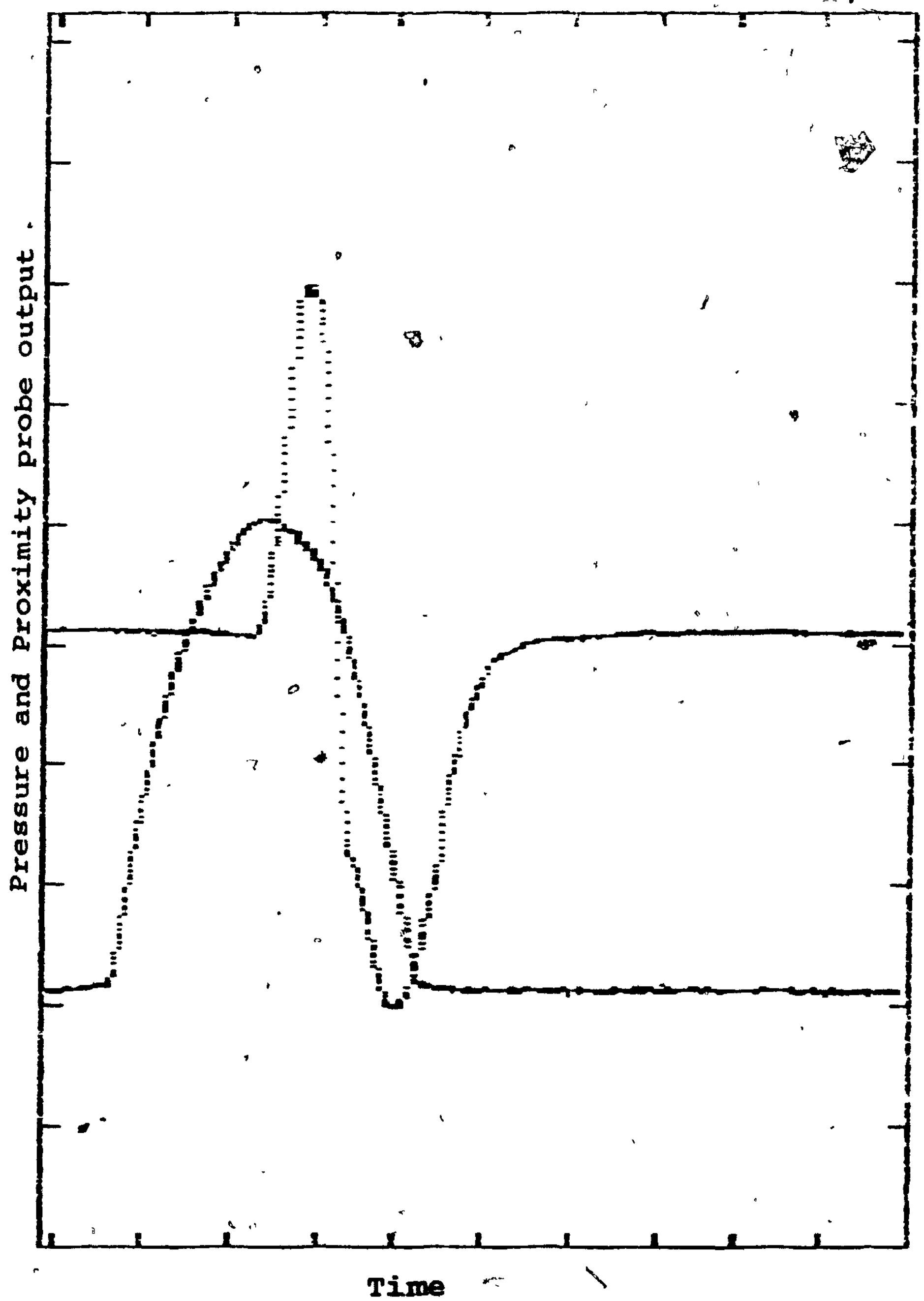
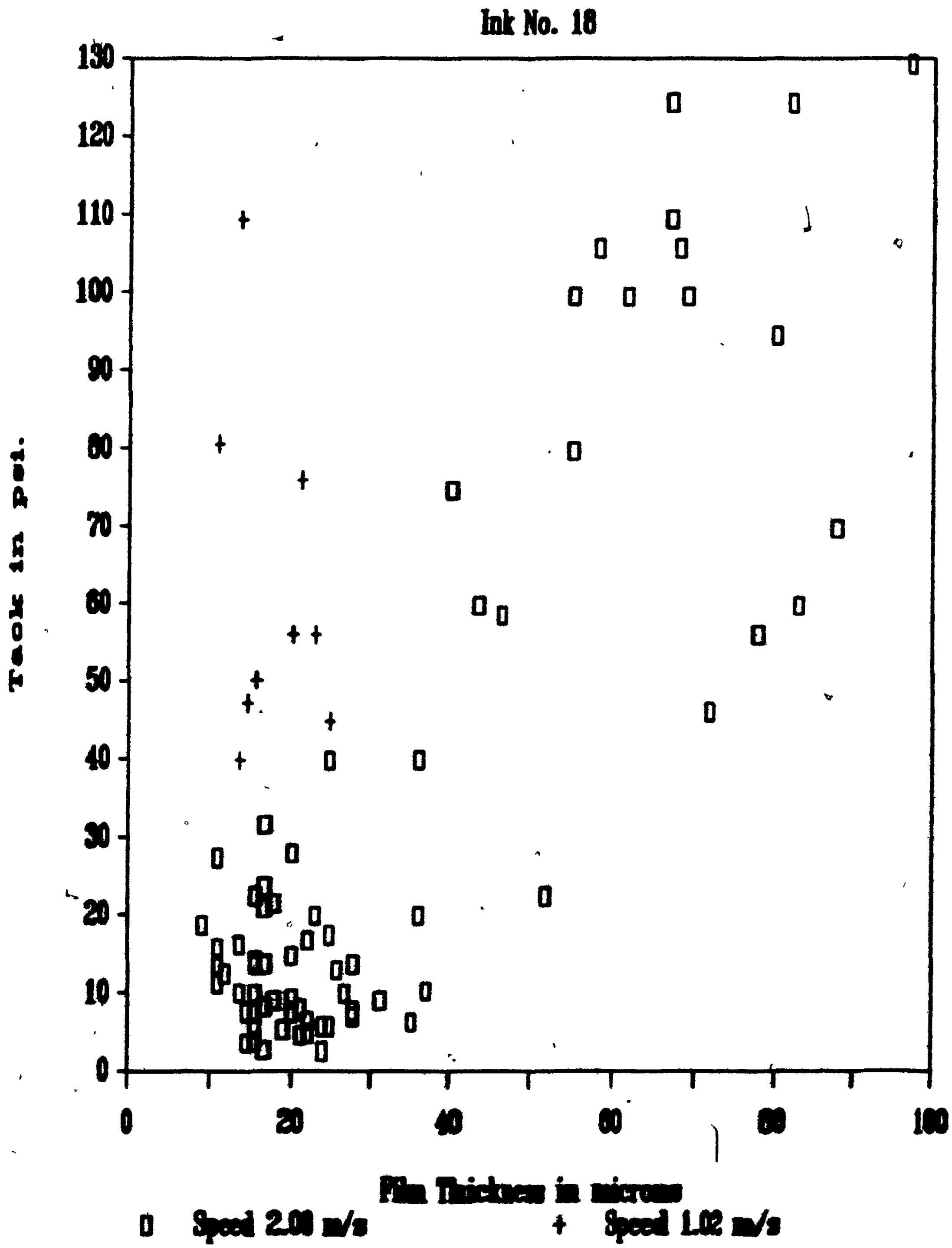


Figure 4.5 Computer printout for the experiment recorded in Figure 4.4.

Tack is defined here as the maximum negative pressure measured by the transducer. Fig. 4.6 shows a plot of tack versus film thickness for ink no. 18 as measured at two different speeds. The results do not seem to show a correlation between tack and film thickness. Low speeds are associated with lower film thickness, because these conditions both result from low angles of inclination of the plane. However, for a given thickness, the lower speed results show larger tack. For a small range of film thickness we cannot conclude anything about the variation of tack with film thickness, but considering a wide range of film thickness we can see a general tendency of increasing tack with film thickness.

Maximum positive pressure versus film thickness for the same experiments on ink no. 18 and at two different speeds is plotted in Fig. 4.7. For clarity, an expanded view of the same plot is shown in Fig. 4.8. It can be seen that the maximum positive pressure in the nip varies with film thickness in the same way as the tack. This suggests some proportionality between the positive and the negative (tack) pressure peaks. This is supported by the results shown in Figs. 4.9 and 4.10. Fig. 4.9 is a plot of the maximum positive pressure versus tack (maximum negative pressure). An expanded view of the same plot is shown in Fig. 4.10. However, as we can see from these figures, the relationship is not linear.



<u>Figure 4.6</u> Tack versus film thickness for ink no. 18 at two different speeds.

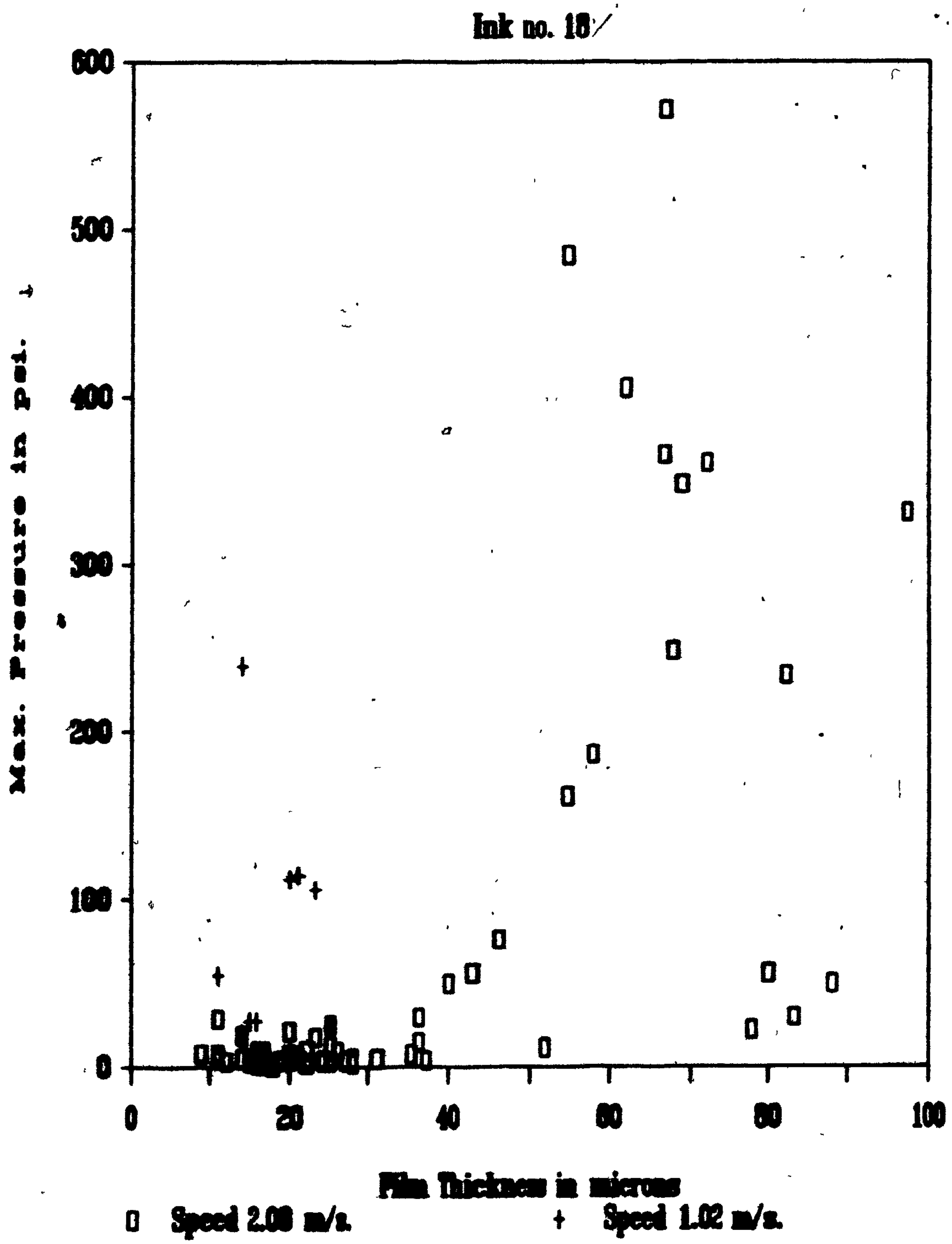


Figure 4.7 Positive pressure variation with film thickness for ink no. 18 and two different speeds.

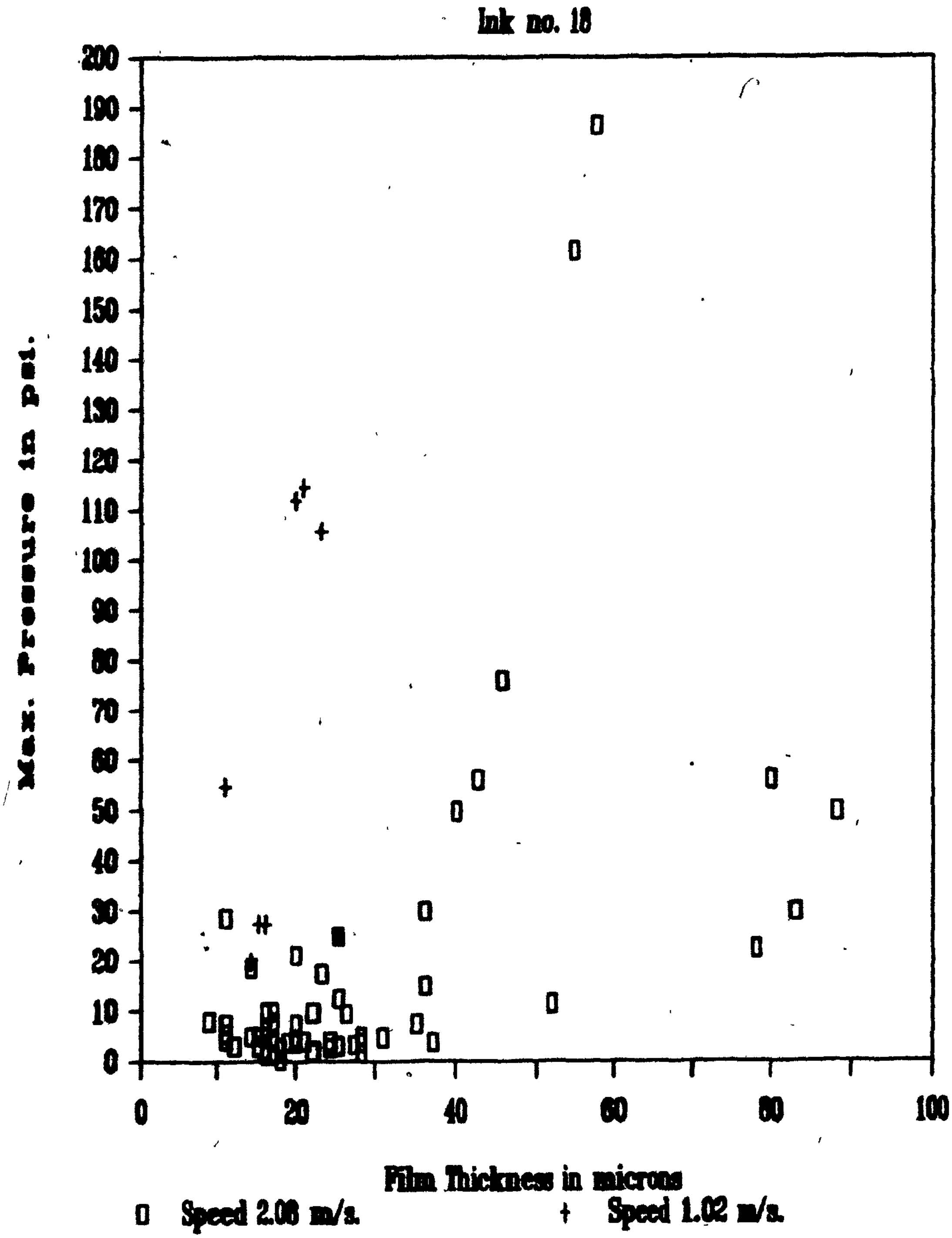


Figure 4.8 Expansion of Figure 4.7.

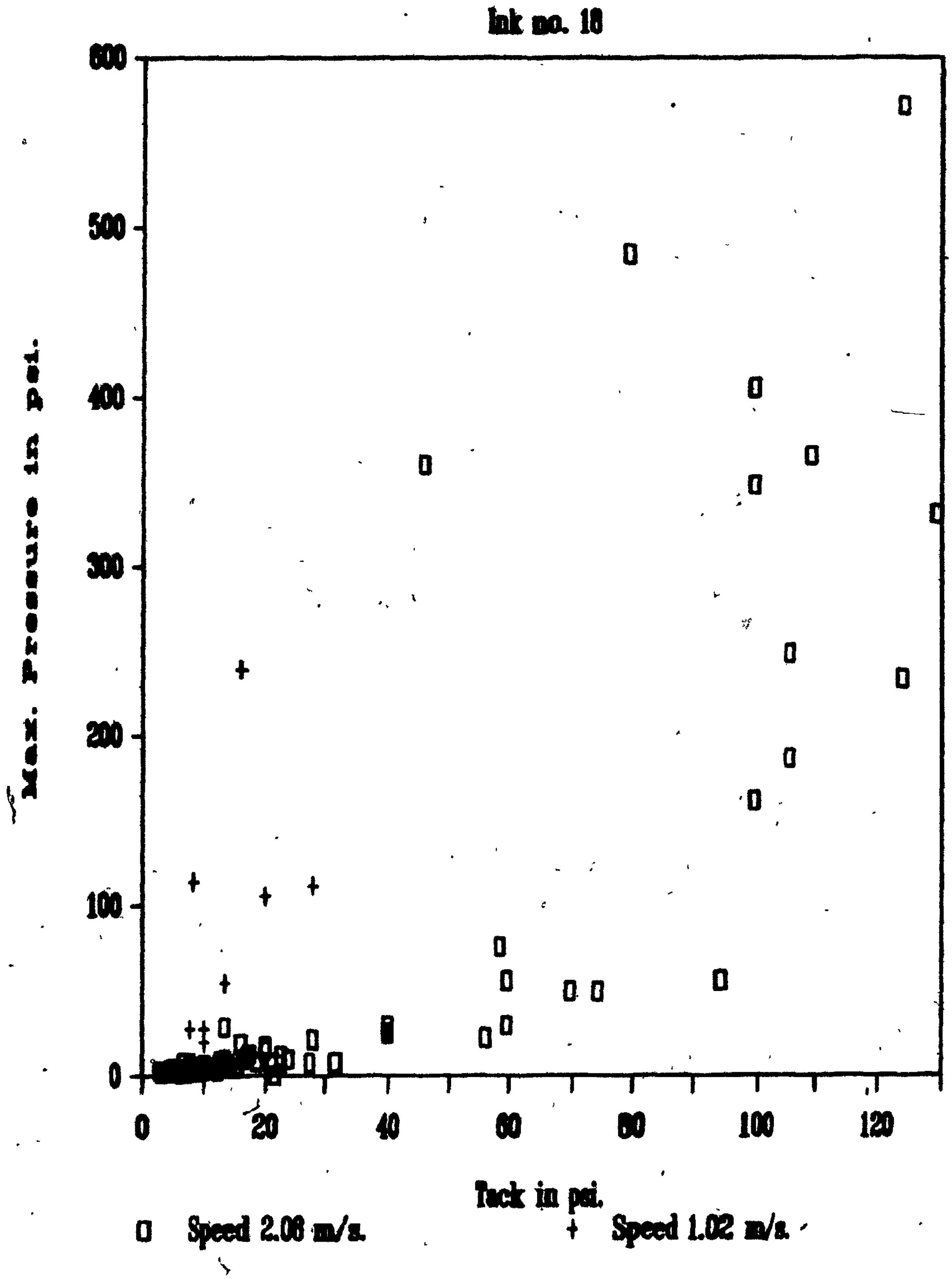


Figure 4.9 Relationship between maximum positive pressure and tack (maximum negative pressure) for ink no. 18 and two different speeds.

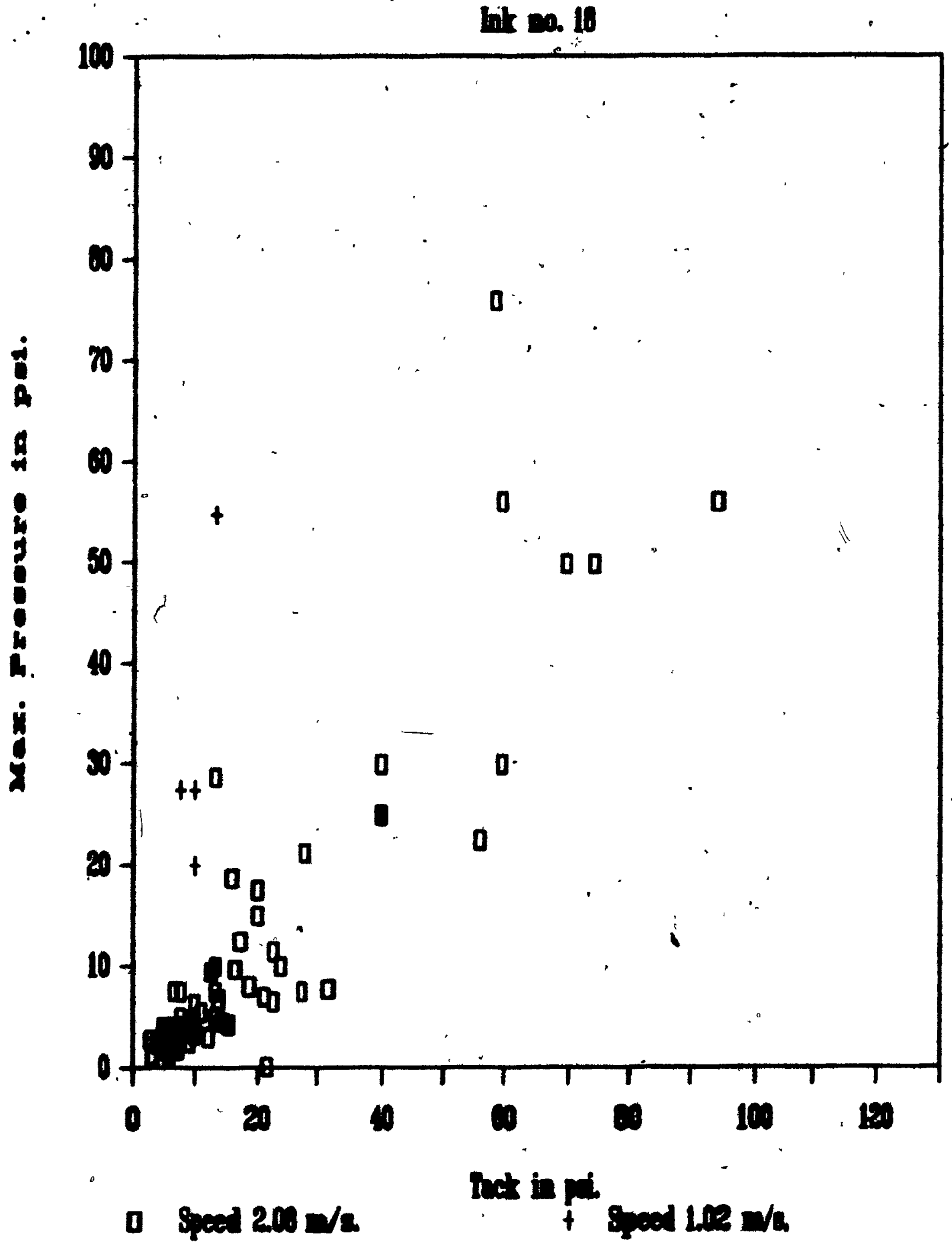


Figure 4.10 Expansion of Figure 4.9.

Almost the same type of results are obtained for ink no. 2 as shown in Figs. 4.11 to 4.13.

An effort was made to explain the high degree of scatter in the tack measurements. One thought was that inks have time dependent rheological properties and that this might affect their splitting behaviour. To study time dependency in the tack measurements, the time sequence of the measurement was noted. The results are shown in Figs. 4.14 and 4.15. As we can see there is no evident relationship between tack and time. Figs. 4.16 and 4.17 also show the irrelevance of time in the tack - maximum pressure relationship.

Another possibility is that the cylinder is slipping rather than rolling over the transducer so that the splitting mechanism is different from the one desired. An attempt was made to reduce the slip by placing the core of the cylinder eccentric to the shaft center, although this would not totally eliminate slip. To reduce the slip to an acceptable level, the inertia of the outer shell should be very small compared to that of the central core. In other words, the mass of the shell should be very small compared to that of the core. Such a design is difficult to achieve.

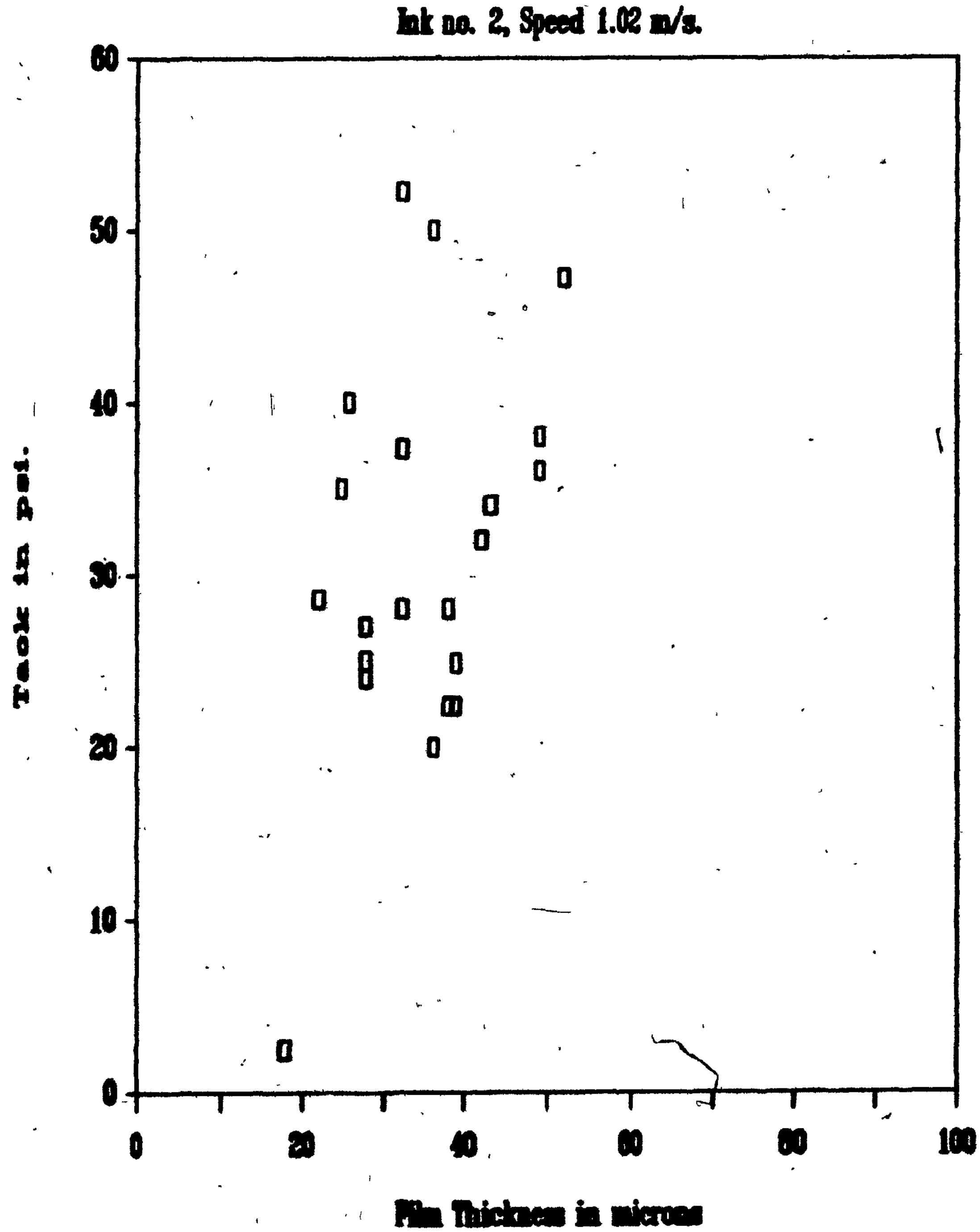


Figure 4.11 Tack - film thickness relationship for ink no. 2 at a speed of 1.02 m/s.

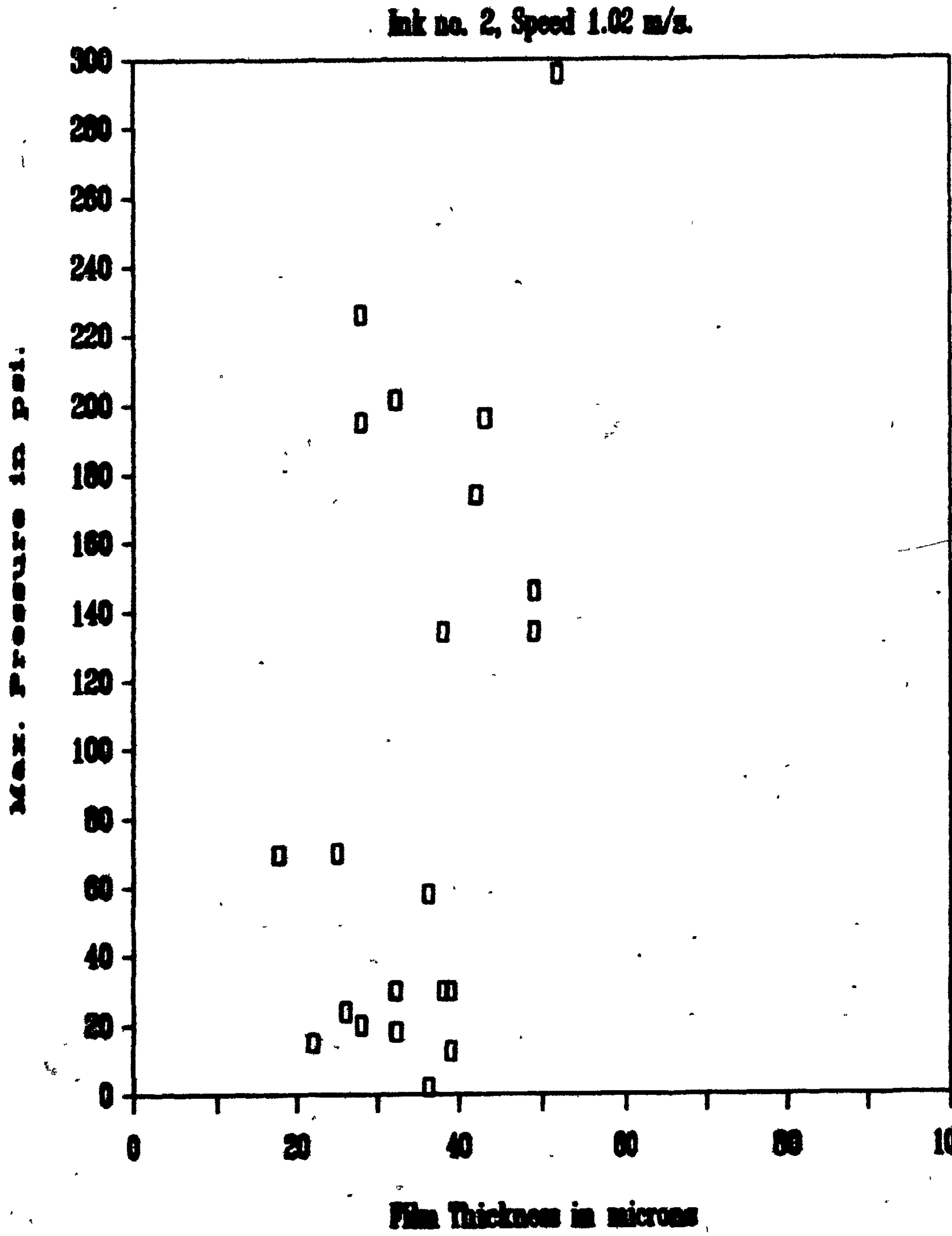


Figure 4.12 Positive pressure variation with film thickness for ink no. 2 and a speed of 1.02 m/s.

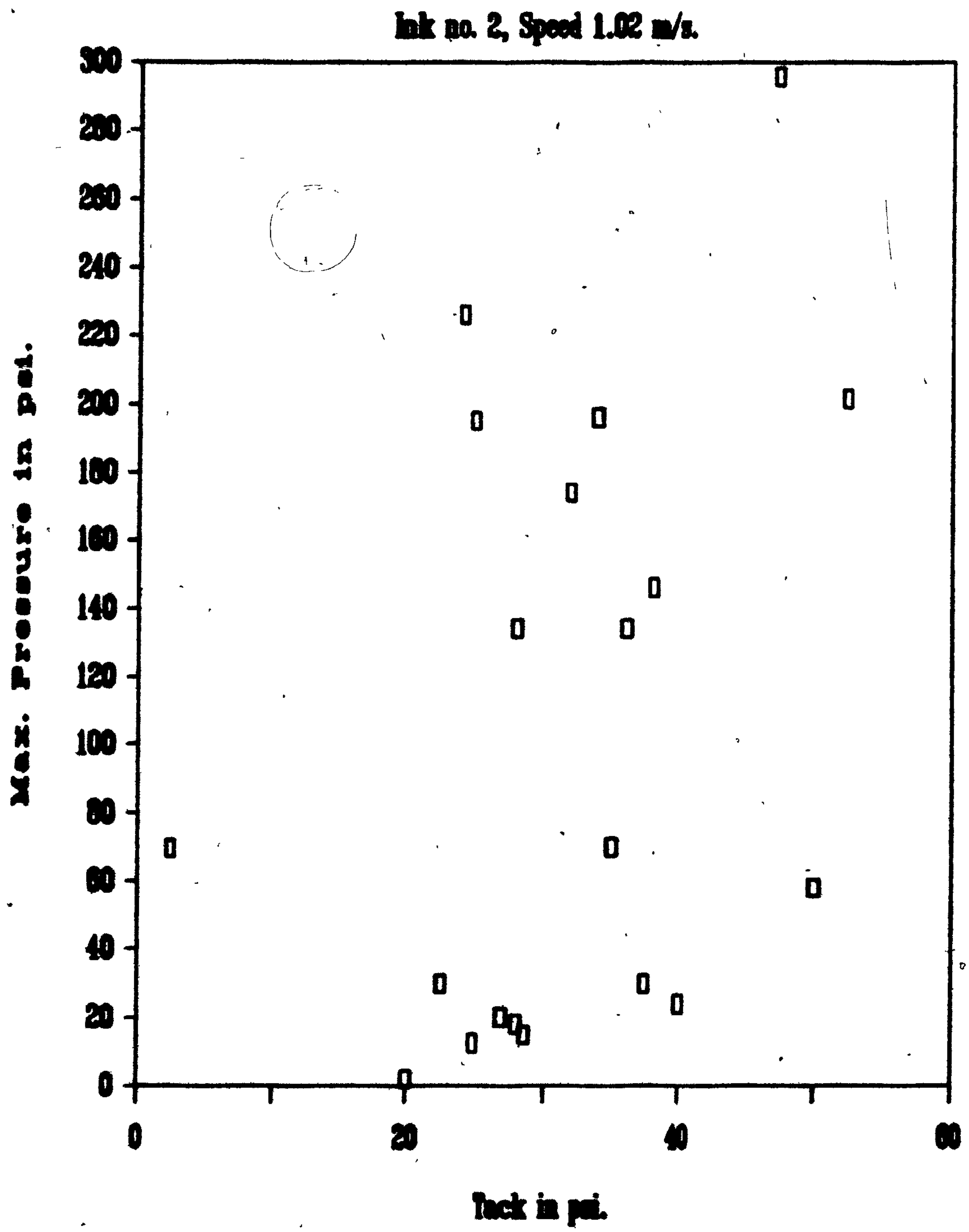


Figure 4.13 Relationship between maximum positive pressure and tack (maximum negative pressure) for ink no. 2 and at a speed of 1.02 m/s.

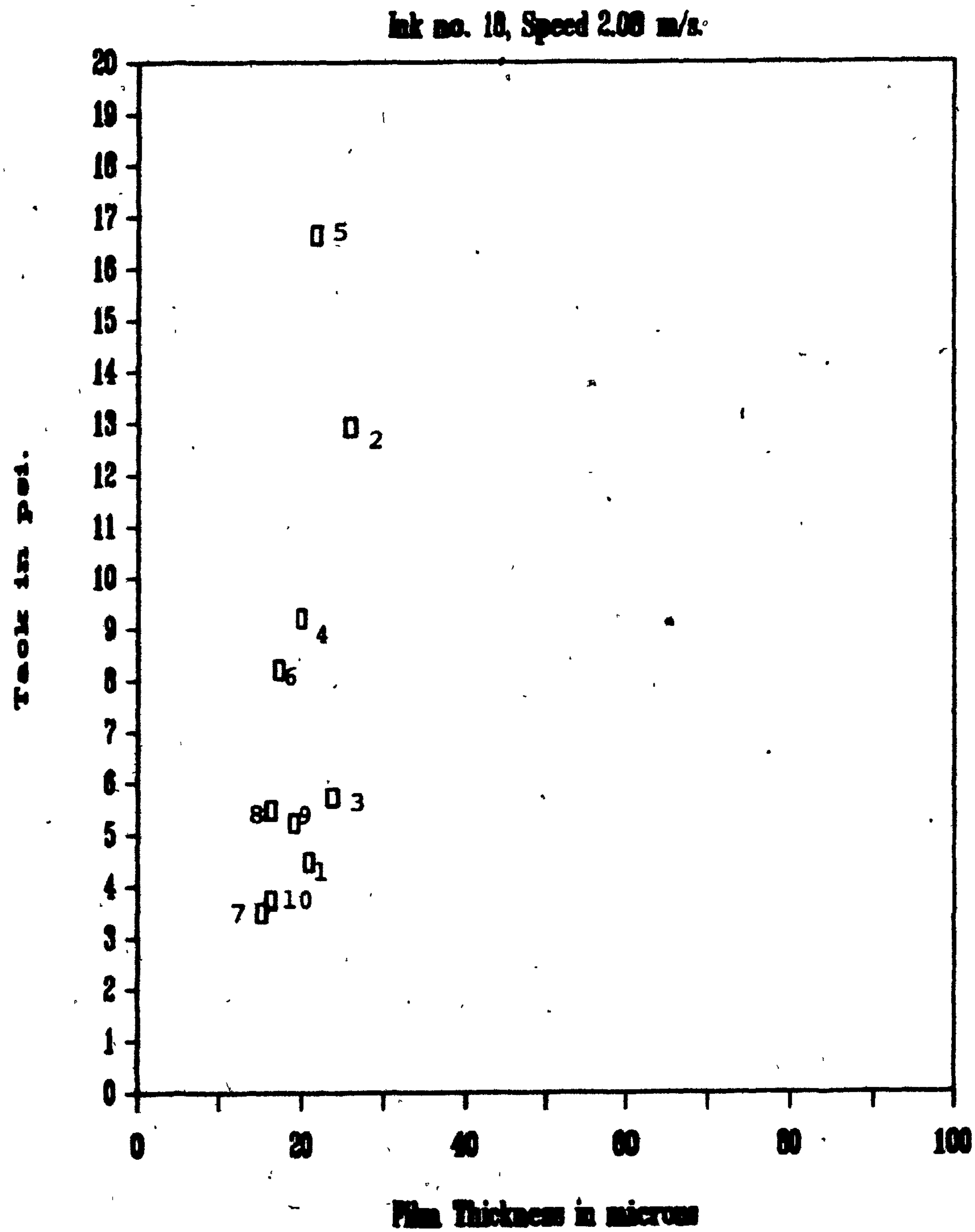


Figure 4.14 Effect of time sequence on tack and film thickness measurements.

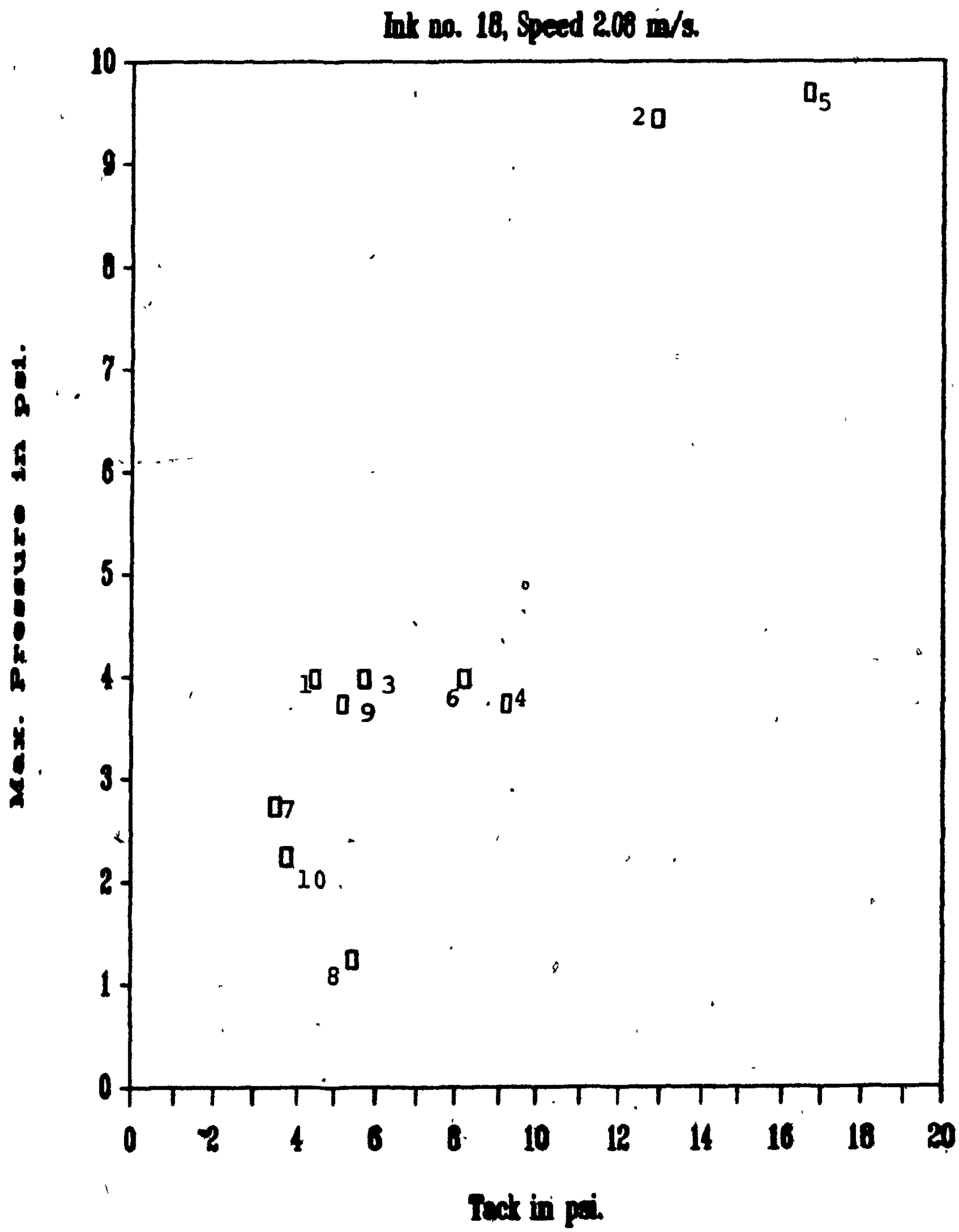
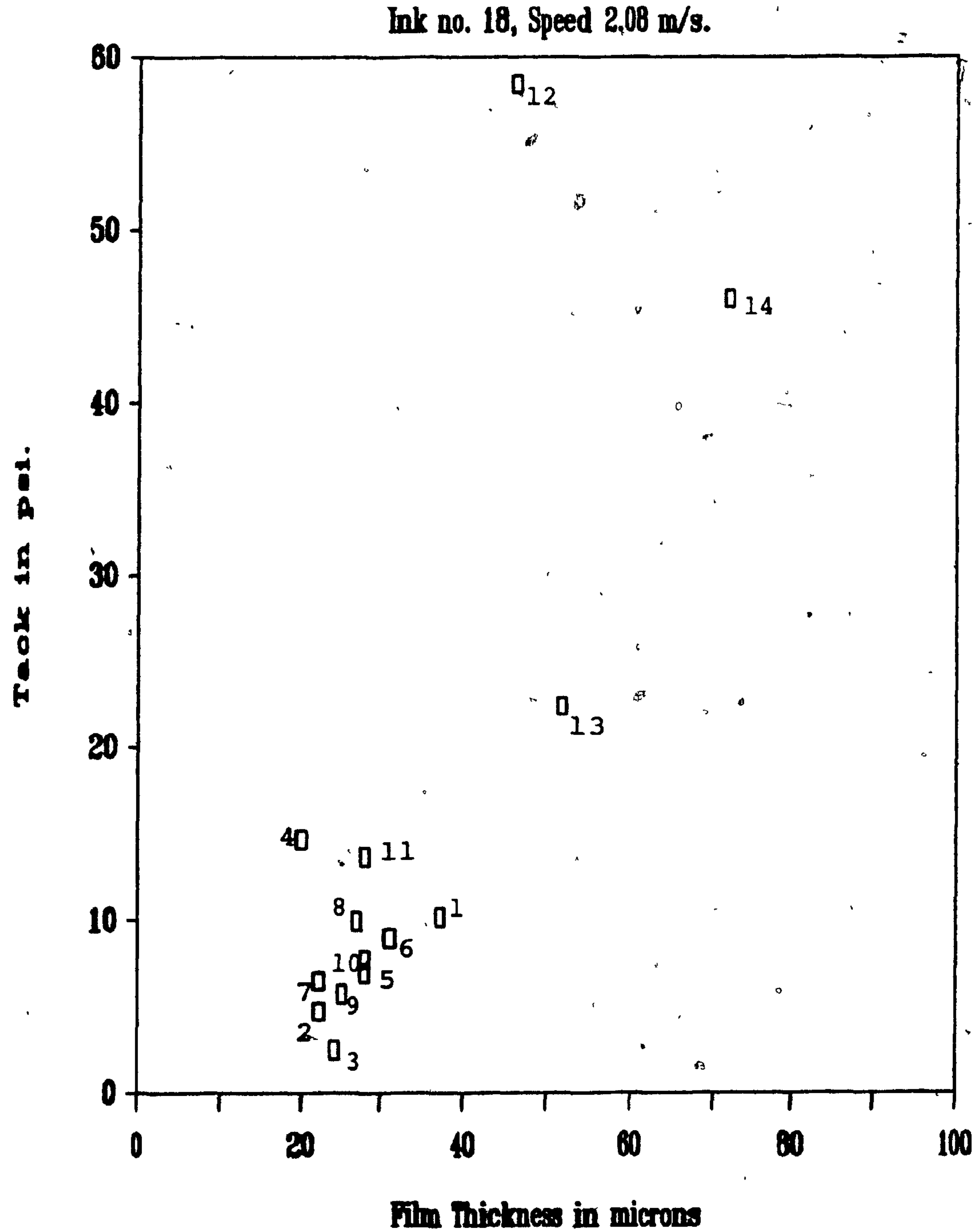
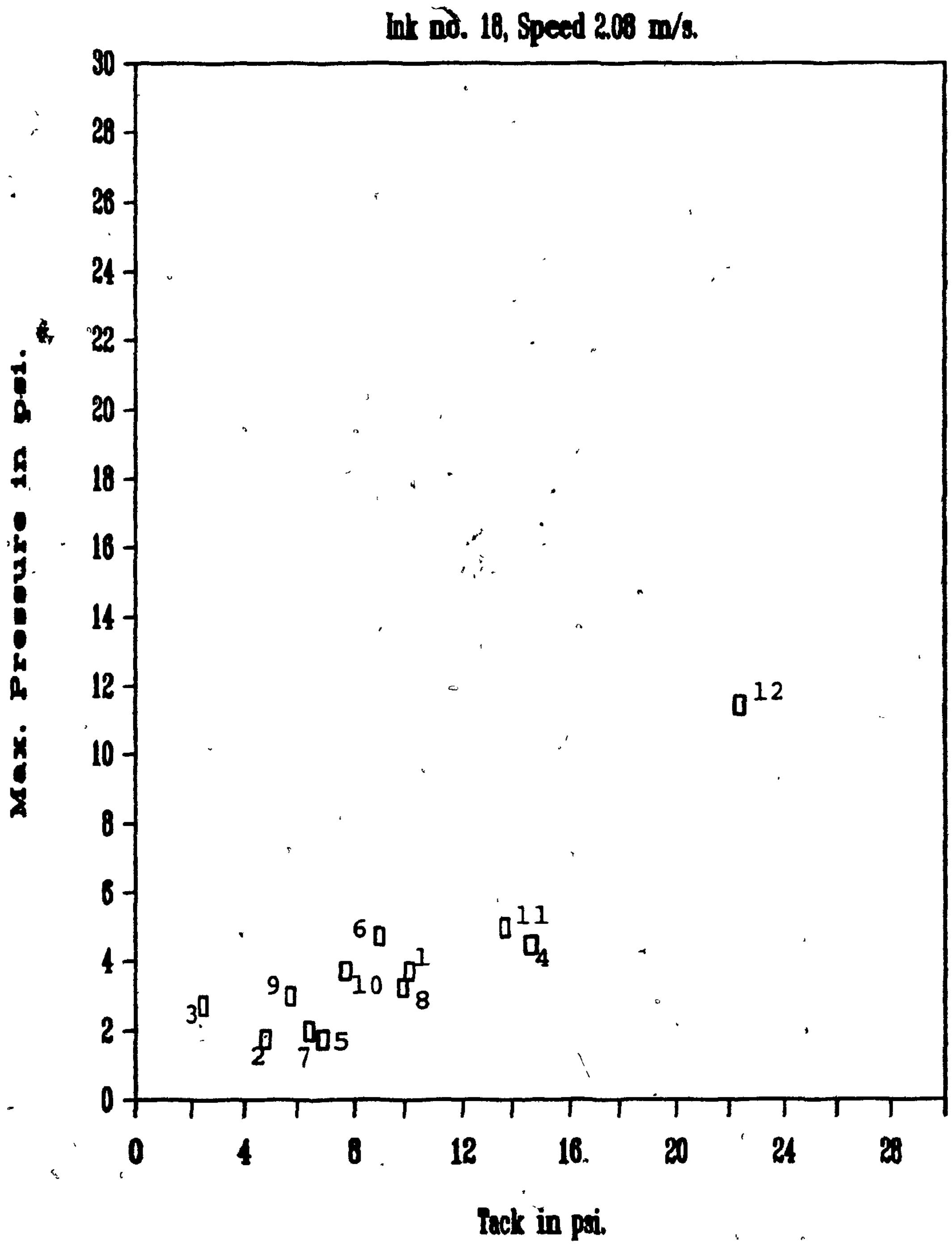


Figure 4.15 Effect of time sequence on pressure peak relationship.



<u>Figure 4.16</u> Effect of time sequence on tack and film thickness measurements.



<u>Figure 4.17</u> Effect of time sequence on pressure peak relationship.

4.1 Proposed Improvements Of The Technique

The technique needs to be improved in following areas.

1. Improve ease of cleaning.
2. Develop a method to quickly apply a uniform coating of ink to the roller and plane.
3. Increase the durability of the apparatus and resistance to surface denting.
4. Employ a dedicated microprocessor-based data acquisition and analysis system.

It would be a good idea to keep the heavy roller attached somehow to the device so that it cannot be removed from the apparatus. This would make it more durable, because it reduces the possible number of incidents of scratching or denting the surface of the roller. Also, it would increase the operator's safety because there would be no way he or she could drop the roller onto the floor. However, some provision would have to be made to remove the roller to do mechanical work like machining or polishing.

By some means the roller should be lifted about one centimeter above the plane to aid in its cleaning. To minimize the need to touch the metal roller and to maintain the independence of the machine from an electrical motor, one of the shaft ends on the cylinder should be able to accept some form of crank or handle to turn the roller. This would make clean up easier and faster, as well as eliminating the need to remove the roller from the machine.

Currently, the base plate of the apparatus has an adjustable leg, and a protractor with bubble indicator is used to level the whole instrument. This technique ensures that an even film thickness results from the roller moving down the plane. Perhaps a fixed circular bubble indicator would be more convenient than the protractor.

Uniform ink distribution is a serious problem with the apparatus. The rubber roller currently used does not ensure uniform ink distribution. It should be replaced with some other device to get uniform ink distribution over the plane. A knife moving up and down the plane and maintaining a constant gap between the plate and knife edge is one possibility. But in this case, controlling the gap in the micron range is difficult. Another alternative is to mount a small rubber roller on top of the present roller in such a way that it reciprocrates while turning. This would help in obtaining a uniform distribution.

At the present time the output signals from the apparatus are captured and stored by the digital oscilloscope, and the computer then acquires and analyzes the data. These two expensive instrumental systems could be replaced by an inexpensive microprocessor-based data acquisition and analysis system. Ideally this dedicated system would receive analog outputs from the apparatus, convert them into digital form, store the data and after suitable computation them display the results.

Chapter 5

MEASUREMENT OF TACK IN AN ACTUAL PRINTING NIP

The technique developed in this research could be used to measure the tack in an actual printing nip, if a transducer were to be mounted on one side of the nip. A laboratory printing press that could be used for this kind of experiment is shown in Fig. 5.1, and an inking apparatus that could be used with the press is shown in Fig. 5.2. Such a press is currently being fabricated at the Pulp and Paper Research Institute of Canada.

5.1 Principle Of Operation

A printing plate is inked by an inking apparatus and the amount of ink transferred to the plate is determined by weighing the plate before and after inking. The plate is attached to the plate cylinder of the printing press over

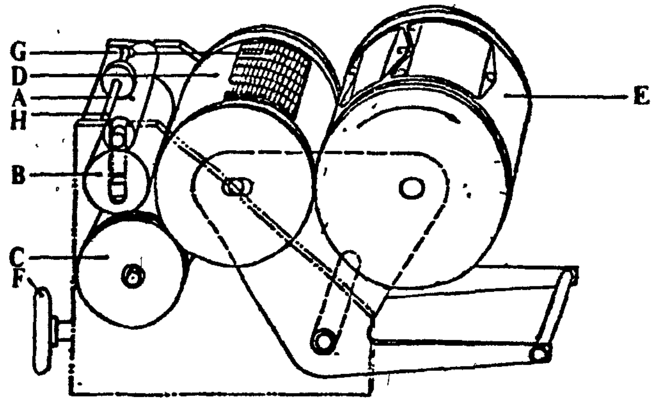


Figure 5.1 Inking apparatus for laboratory printing press.
A: Steel roll.
B: Oscillating plastic-covered roll.
C: Ink-transfer roll.
D: Cylinder.
E: Steel cylinder on which the printing plates are fastened.
F: Device for pressure regulation.
G: Ink-transfer plate.
H: Ink leveller.

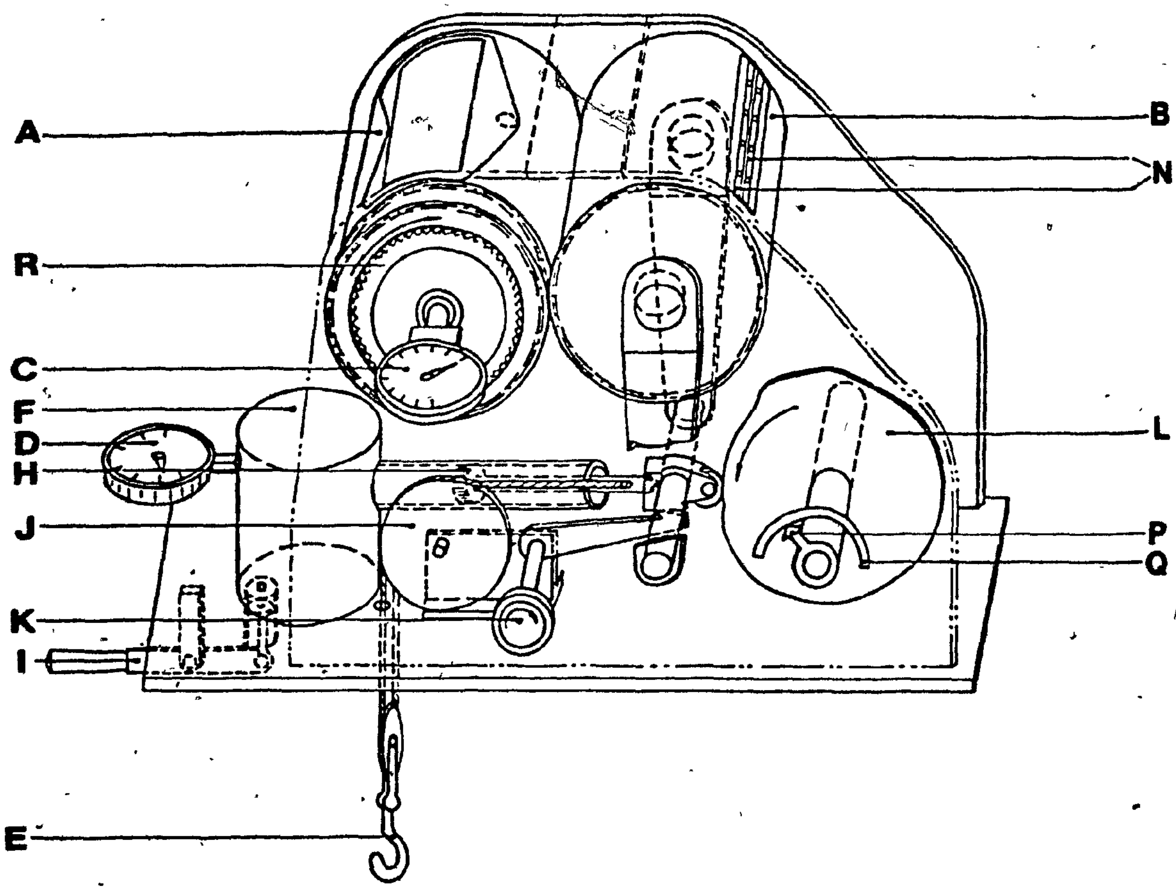


Figure 5.2 Laboratory printing press.

A: Plate cylinder
B: Blanket cylinder
C: Tachometer
D: Manometer
E: Balance device
F: Pressure chamber
H: Piston
I: Pump
J: Pulley
K: Knob
L: Cam plate
N: Fastening device
P: Arrow
Q: Scale
R: Handwheel

the pressure transducer mounted on the plate cylinder. The printing to the blanket cylinder will be performed under specified conditions. The plate will be removed from the plate cylinder after printing to the blanket. The image will be back-printed from the blanket to the plate surface, and tack measurements will be made. The amount of printing ink transferred to the blanket, and the film thickness is calculated by weighing the plate before and after printing, and by taking into account the printing area.

5.2 The Inking Apparatus

The inking apparatus consists of:

1. An ink distribution unit with the rolls A, B and C; B is an oscillating plastic roll. The unit includes an ink leveller H, which moves axially over the roll A.

2. A cylinder D, 84 mm in diameter, to which an ink-transfer plate G of polyurethane polymer is attached. This plate is 2.00 $\pm$ 0.15 mm thick and has a hardness of $30^{\circ} \pm 5^{\circ}$ Shore. The peripheral velocity of the cylinder is 0.85 m/s.

3. A steel cylinder E, 112 mm in diameter, to which four

printing plates can be attached. The position of each plate is marked with its number.

By means of a wheel F the rolls C, D and E, which are connected by gears, can be brought into contact with - and separated from - each other. The peripheral velocity of the cylinder E is 0.85 m/s.

5.3 Laboratory Printing Press

The printing press consists of two cylinders, A and B, each 140 mm in diameter. The rotation of the plate cylinder A and the blanket cylinder B is synchronized by gears. To the plate cylinder four printing plates can be attached. A pressure transducer with cylinderical-convex diaphragm will be mounted on the plate cylinder at the location of the plate so that when the plate is attached to the plate cylinder it covers the transducer. The blanket cylinder is covered with a rubber blanket, 1 mm in thickness, consisting of a 0.70 mm web combined with a 0.30 mm synthetic rubber sheet with a hardness of $85^{o} \pm 3^{o}$ Shore. The blanket is mounted on the cylinder by means of a fastening device N. The pressure between the plate cylinder and the blanket cylinder can be varied by means of a pneumatic system consisting of a pressure chamber F, a piston H, a pump I and a lever system connected to the blanket cylinder. The blanket cylinder is brought into contact with the plate cylinder by means of a lever system including a knob K and a cam plate L. The peripheral speed of the plate cylinder A is shown on a tachometer C. The pressure of the pneumatic system indicated on the manometer D is calibrated as described in Appendix F, by means of a balance device E.

The printing plate that is to be used for the experiments is made of phosphor bronze, 0.200 ± 0.015 mm thick, (SIS 145428-07) with a 100 percent printing area. The surface roughness should not exceed 0.5 microns.

A storage oscilloscope is to be used to record the output from the pressure transducer to measure ink tack.

5.4 Procedure

5.4.1 Inking of the printing plates

Clean the whole inking apparatus and both sides of the printing plates with petroleum benzine (boiling point 45 to 60°C) and surgical cotton. Polish the plates with dry surgical cotton. Weigh the plates and mount each one in place in the inking apparatus - the numbers on the plates should correspond to those in the inking apparatus. Avoid touching the printing area of the plates, and handle them only at their edges. By means of a syringe or an ink pipette apply about 2 ml of printing ink to roll A. With the pressure between the ink-transfer roll C and cylinder D and E released start the inking apparatus. Allow the cylinders to make a few revolutions, apply pressure by means of the pressure regulation device F and let the apparatus run for at least 20 seconds. Release the pressure at the moment when the ink-transfer plate G is no longer in contact with any of the printing plates and stop the apparatus. Remove printing plate 1 and weigh it. Ink the remaining three plates as described above.

The amount of ink on a plate depends on the amount removed from the rolls A and B during each inking stage. To ink a plate the apparatus should be run for about 15 seconds.

5.4.2 Printing on the blanket

Fix the inked printing plates in their appropriate positions on the plate cylinder. Start the press and regulate the speed to a certain value (RPM) as read on tachometer C, corresponding to the desired peripheral velocity. Increase the pressure in the pressure chamber F with the pump until the manometer D indicates a value corresponding to a linear pressure of 157 N/cm (15.7 kgf/cm) between the plate cylinder A and the blanket cylinder B (See Appendix F). Let the printing apparatus run for a few seconds. Start printing. Turn the knob K counterclockwise, keep it in position only for a moment, to avoid printing twice. Stop the apparatus and remove the plates. Weigh the plates.

5.4.3 Measuring tack

Perform the printing as earlier described, but now without the plates and from the blanket to the transducer-bearing plate surface. Record the transducer output on the oscilloscope and calculate the tack.

5.4.4 Film thickness calculations

Calculate the amount of ink transferred to the blanket from the expression

$$X = \frac{G' - G}{A}$$

Where
A = the printed area, m^2
G = the weight of the printing plate after printing, g
G' = the weight of the printing plate before printing, g
and X = the amount of printing ink transferred, g/m^2.

Calculate the film thickness on the blanket from the expression

$$F = \frac{X}{\rho A}$$

Where F = film thickness, cm
and ρ = density of the ink, g/cm^3.

Chapter 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

1. An apparatus was designed, constructed and developed to evaluate the ability of inks to support tensile stresses during film splitting in a printing nip. It was assumed that 'tack' is associated with the maximum tensile force supported by an ink film just before film splitting occurs.

2. A miniature pressure transducer was mounted on one face of a simulated printing nip to record accurately the normal forces occuring under printing conditions. To measure the film thickness and speed of the apparatus a proximity probe was also mounted on the

same face.

3. The pressure output and the proximity output from the apparatus were recorded and stored on a digital storage oscilloscope. This stored waveforms were downloaded to a personal computer interfaced with the oscilloscope and the computer did calculations and printed results.

4. The apparatus was used for tack measurements on two ink formulations and at two different speeds. It is shown that the speed measurements are reliable and accurate. Although the results do not show any correlation between tack and film thickness, the pressure profile in the nip is comparable to that hypothesized by previous workers. It is shown that there is no time dependency in the tack measurements.

6.2 Recommendations

1. Further work on the apparatus has to be done to study the relationship between tack, film thickness and maximum positive pressure.

2. It is desirable to study the effect of ink composition on tack.

3. It is recommended to design a support system to keep the heavy roller attached to the apparatus to make it more durable and safe.

4. The ease of cleaning needs to be improved by modification of the apparatus.

5. The rubber roller used currently to apply ink to the plate surface should be replaced with some other device to obtain a more uniform ink distribution.

6. The digital storage oscilloscope and the computer could be replaced by an inexpensive microprocessor-based data acquisition and analysis

system.

7. The technique developed in this research could be used to measure the tack in an actual printing nip, if a transducer were to be mounted on one side of the nip in a laboratory printing press. Such a press is currently being fabricated at the Pulp and Paper Research Institute of Canada.

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Appendix A

NIP VARIABLES

IMPORTANT NIP VARIABLES AND THEIR ORDER OF MAGNITUDE VALUES IN NIP FLOW

VARIABLE	ORDER OF MAGNITUDE	
Ink Film Thickness (characteristic length)	10^{-6}	m
Tangential Roller Velocity	10	m/s
Pressure Maximum	1	MPa
Typical Ink Viscosity Value	10	Pa.s
Typical Ink Density Value	10^{3}	kg/m^{3}
Nip Residence Time (characteristic time)	10^{-3}	s
Ink - Roller Interfacial Surface Tension	10^{-2}	N/m

Appendix B

PROXIMITOR CALIBRATION

Fig B.1 shows the calibration curve for the proximitor, obtained and used in this research.

B.1 Calibration Procedure

The set up for proximity probe calibration is shown in Fig B.2. For proper calibration of the proximity probe, following procedure should be followed.

1. Connect the test equipments as shown in the set up. While connecting power supply observe proper polarity.

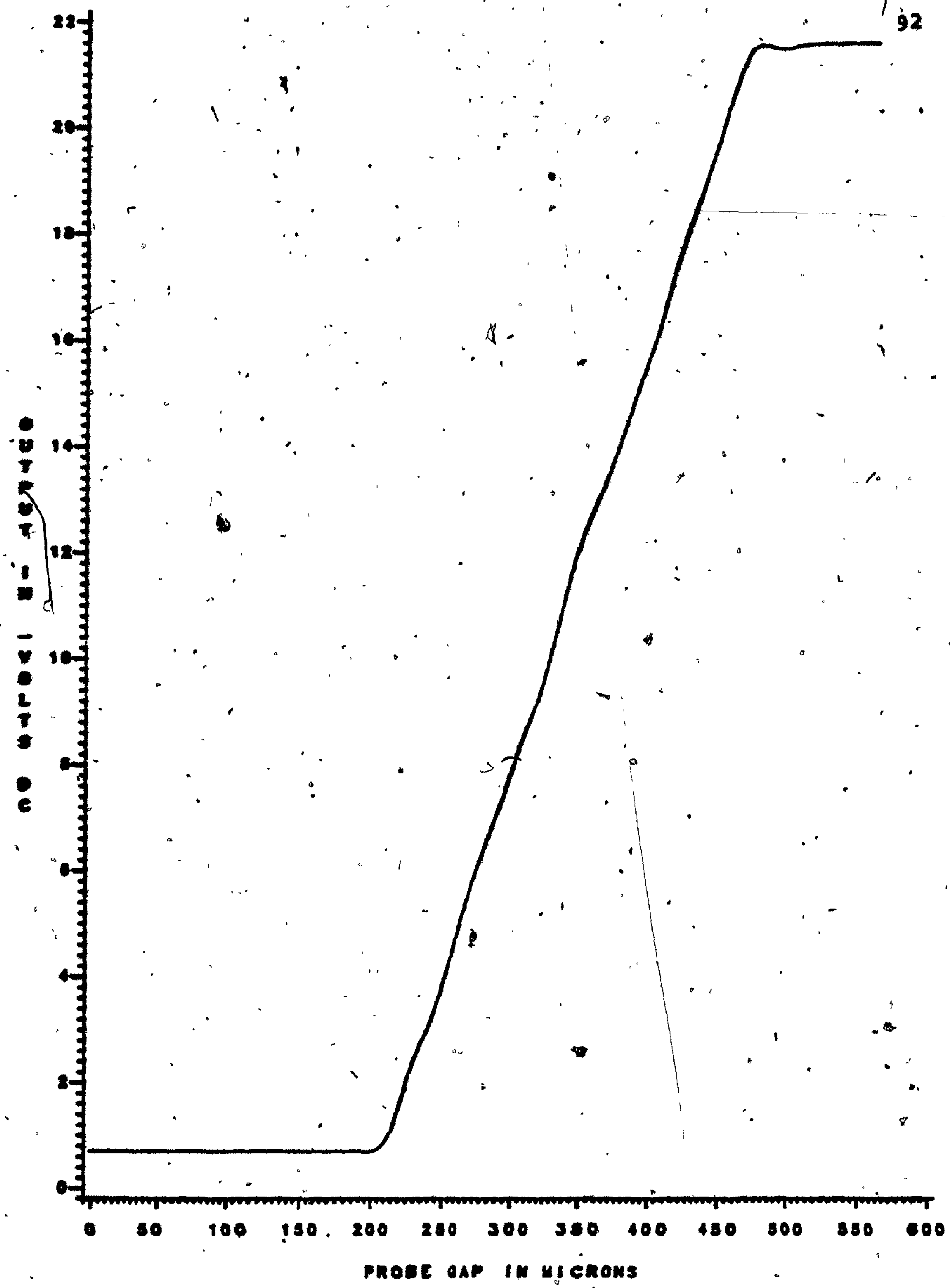


Figure B.1 PROXIMITOR CALIBRATION FOR MILD STEEL TARGET

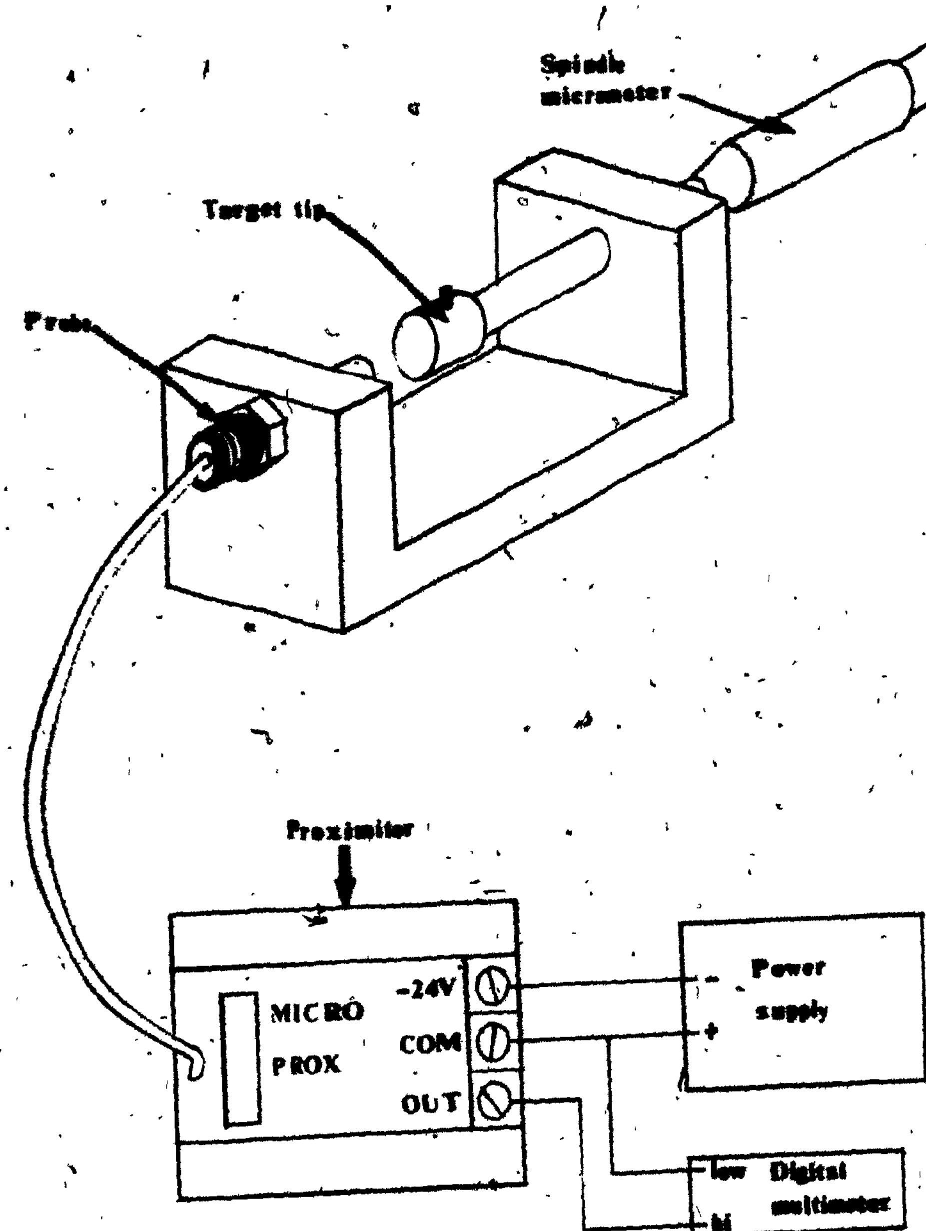


Figure B.2 Proximitor calibration setup.

2. Set the spindle micrometer on the calibration mounting to zero.

3. Mount and adjust the probe on the opposite end, so that the probe tip is touching the target tip on the spindle of micrometer and reading on the micrometer is zero. Tighten the locking nut on the probe. (Note: The probe tip should be hanging in the mounting bracket for about 8 mm to eliminate error in reading due to the effect of electromagnetic field of the probe on the mounting bracket.)

4. Increase the distance between the probe and target (which should be of the same metal and finish as the cylinder-shell) in certain increments, by adjusting the micrometer and record the distance (the gap) versus output voltage read on the multimeter.

5. Plot the voltage output versus the distance or compare each to the desired calibration curve.

B.2 Recalibration

If the preceding calibration procedure indicates that the transducer is out of tolerance, recalibrate the transducer as follows:

1. Remove the protective assembly and calibration resistor from the proximitor.

2. Connect the variable resistor and perform the preceding calibration procedure until the desired calibration curve is obtained. (Note: Increasing the resistance between the calibration terminals will decrease the absolute value and slop of the calibration curve. Decreasing it will cause the absolute value and slope to increase.

3. When the desired calibration curve is obtained, remove the variable resistor from the calibration terminals and, using the multimeter, measure its resistance. Select a metal-film resistor equal to the measured resistance of the variable resistor.

4. Install the metal-film resistor between the calibration terminals. It is acceptable to connect two metal-film resistors in parallel to obtain the desired resistance value.

5. After the resistor has been soldered between the terminals, the protective assembly must be replaced.

Appendix C

CYLINDER SPEED CALCULATIONS

The geometry of a cylinder rolling over a plate covered with liquid film is shown in Fig. C.1.

The notations used here are,

- R = Radius of the cylinder
- t = Time ($t=0$ at the point of minimum gap)
- θ = Angular Co-ordinate ($\theta = 0$ at $t = 0$)
- $F(t)$ = Gap at time t
- F' = Minimum gap between the cylinder and the plate
- Ω = Angular velocity of the cylinder
- v = Peripheral velocity of the cylinder

From the simple geometrical calculations we can get,

$$F(\theta) = F' + (R - R\cos\theta) \qquad \ldots\ldots(1)$$

But

$$\theta = \Omega t$$

hence

$$F(t) = F' + R(1-\cos\Omega t) \qquad \ldots\ldots(2)$$

Rearranging equation (2)

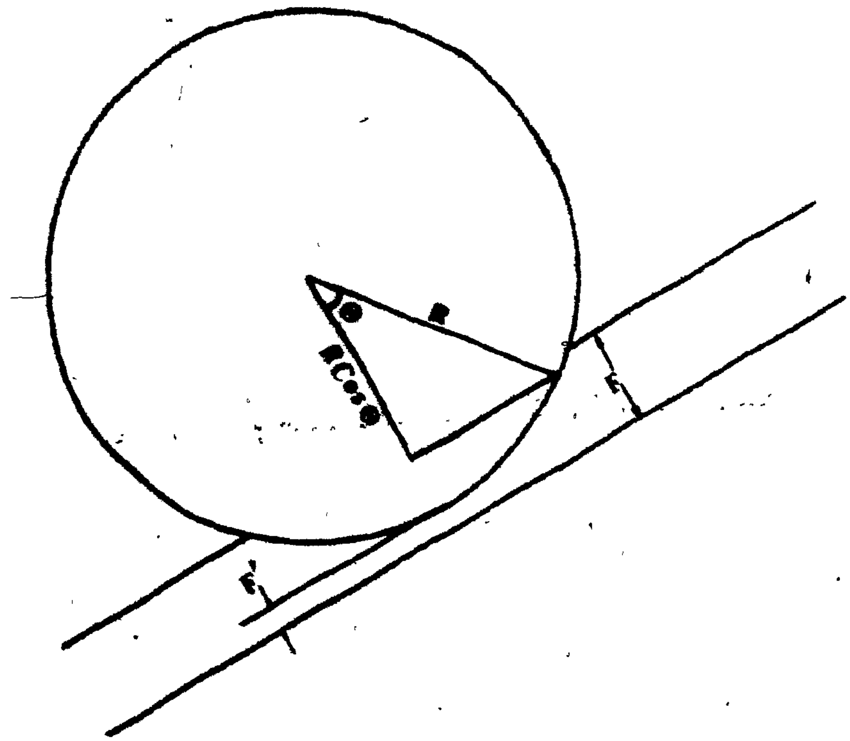


Figure C.1 The geometry of a cylinder rolling over a plate covered with liquid film.

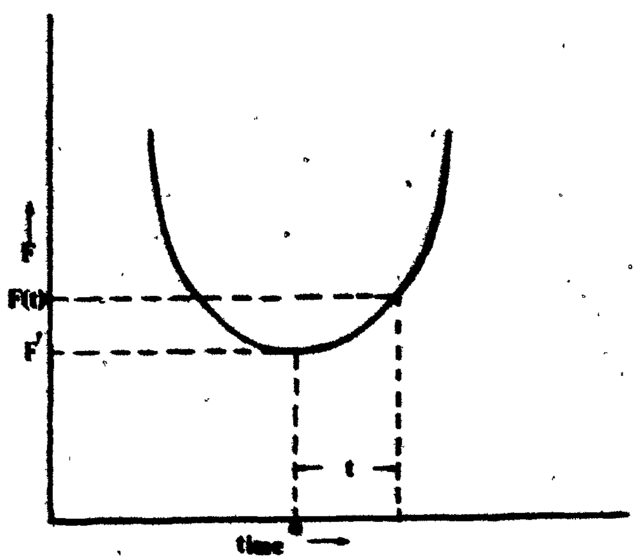


Figure C.2 Typical F vs. time plot.

$$\Omega = 1/t \cos^{-1}(1-(F(t)-F')/R) \qquad ......(3)$$

And peripheral velocity

$$v = \Omega R \qquad ......(4)$$

A typical plot of F vs. t is shown in Fig. C.2. If we measure F' and F(t) at time t away, we can calculate the angular speed and subsequently the peripheral velocity of the cylinder by using equations (3) and (4).

Appendix D

THE BASIC COMPUTER PROGRAM

```
1 CLEAR   ,40000!            ' IBM BASICA Declarations
2 IBINIT1 = 40000!
3 IBINIT2 = IBINIT1 + 3      ' Lines 1 through 6 MUST be
                               included in your program.
4 BLOAD "bib.m",IBINIT1
5 CALL IBINIT1(IBFIND,IBTRG,IBCLR,IBPCT,IBSIC,IBLOC,IBPPC,
       IBBNA,IBONL,IBRSC,IBSRE,IBRSV,IBPAD,IBSAD,IBIST,IBDMA,
       IBEOS,IBTMO,IBEOT,IBRDF,IBWRTF)
6 CALL IBINIT2(IBGTS,IBCAC,IBWAIT,IBPOKE,IBWRT,IBWRTA,IBCMD,
       IBCMDA,IBRD,IBRDA,IBSTOP,IBRPP,IBRSP,IBDIAG,IBXTRC,
       IBRDI,IBWRTI,IBRDIA,IBWRTIA,IBSTA%,IBERR%,IBCNT%)
7 REM Optionally include the following declarations in your
8 REM program. They provide appropriate mnemonics by which
9 REM to reference commonly used values.  Some mnemonics
10 REM (GET%, ERR%, END%, ATN%) are preceded by "B" in order
11 REM to distinguish them from BASICA keywords.
12 REM
13 REM GPIB Commands
14 UNL% = &H3F       ' GPIB unlisten command
15 UNT% = &H5F       ' GPIB untalk command
16 GTL% = &H1        ' GPIB go to local
17 SDC% = &H4        ' GPIB selected device clear
18 PPC% = &H5        ' GPIB parallel poll configure
19 BGET% = &H8       ' GPIB group execute trigger
20 TCT% = &H9        ' GPIB take control
21 LLO% = &H11       ' GPIB local lock out.
22 DCL% = &H14       ' GPIB device clear
23 PPU% = &H15       ' GPIB ppoll unconfigure
24 SPE% = &H18       ' GPIB serial poll enable
25 SPD% = &H19       ' GPIB serial poll disable
26 PPE% = &H60       ' GPIB parallel poll enable
27 PPD% = &H70       ' GPIB parallel poll disable
28 REM
29 REM GPIB status bit vector
30 REM global variable IBSTA% and wait mask
31 BERR% = &H8000    ' Error detected
32 TIMO% = &H4000    ' Timeout
33 BEND% = &H2000    ' EOI or EOS detected
```

```
34 SRQI% = &H1000   ' SRQ detected, 6#
35 RQS% = &H800     ' Device needs service
36 CMPL% = &H100    ' I/O completed
37 LOK% = &H80      ' Local lockout state
38 REM% = &H40      ' Remote state
39 CIC% = &H20      ' Controller-In-Charge
40 BATN% = &H10     ' Attention asserted
41 TACS% = &H8      ' Talker active
42 LACS% = &H4      ' Listener active
43 DTAS% = &H2      ' Device trigger state
44 DCAS% = &H1      ' Device clear state
45 REM
46 REM Error messages returned in global variable IBERR%
47 EDVR% =  0       ' DOS error
48 ECIC% =  1       ' Function requires GPIB-PC to be CIC
49 ENOL% =  2       ' Write function detected no Listeners
50 EADR% =  3       ' Interface board not addressed correctly
51 EARG% =  4       ' Invalid argument to function call
52 ESAC% =  5       ' Function requires GPIB-PC to be SAC
53 EABO% =  6       ' I/O operation aborted
54 ENEB% =  7       ' Non-existent interface board
55 EOIP% = 10       ' I/O operation started before previous
                      operation completed
56 ECAP% = 11       ' No capability for operation
57 EFSO% = 12       ' File system operation error
58 EBUS% = 14       ' Command error during device call
59 ESTB% = 15       ' Serial poll status byte lost
60 ESRQ% = 16       ' SRQ remains asserted
61 REM
62 REM EOS mode bits
63 BIN% = &H1000    ' Eight bit compare
64 XEOS% = &H800    ' Send EOI with EOS byte
65 REOS% = &H400    ' Terminate read on EOS
66 REM
67 REM Timeout values and meanings
68 TNONE% =   0     ' Infinite timeout (disabled)
69 T10US% =   1     ' Timeout of 10 us (ideal)
70 T30US% =   2     ' Timeout of 30 us (ideal)
71 T100US% =  3     ' Timeout of 100 us (ideal)
72 T300US% =  4     ' Timeout of 300 us (ideal)
73 T1MS% =    5     ' Timeout of 1 ms (ideal)
74 T3MS% =    6     ' Timeout of 3 ms (ideal)
75 T10MS% =   7     ' Timeout of 10 ms (ideal)
76 T30MS% =   8     ' Timeout of 30 ms (ideal)
77 T100MS% =  9     ' Timeout of 100 ms (ideal)
78 T300MS% = 10     ' Timeout of 300 ms (ideal)
79 T1S% =    11     ' Timeout of 1 s (ideal)
80 T3S% =    12     ' Timeout of 3 s (ideal)
81 T10S% =   13     ' Timeout of 10 s (ideal)
82 T30S% =   14     ' Timeout of 30 s (ideal)
83 T100S% =  15     ' Timeout of 100 s (ideal)
84 T300S% =  16     ' Timeout of 300 s (ideal)
85 T1000S% = 17     ' Timeout of 1000 s (maximum)
```

```
86 REM
87 REM Miscellaneous
88 S% = &H8              ' Parallel Poll sense bit
89 LF% = &HA             ' Line feed character
90 REM
91 REM Application program variables passed to
92 REM GPIB functions
93 REM
94 CMD$ = SPACE$(10)          ' Command buffer
95 RD$ = SPACE$(255)          ' Read data buffer
96 WRT$ = SPACE$(255)         ' Write data buffer
97 BNAME$ = SPACE$(7)         ' Board name buffer
98 BDNAME$ = SPACE$(7)        ' Board or device name buffer
99 FLNAME$ = SPACE$(50)       ' File name buffer
101 DIM LEFT%(1016) 'Array for left channel
                     i.e. pressure data.
102 DIM RIGHT%(1016) 'Array for right channel
                     i.e. proximity data.
103 INK=2: ANGLE=60 :LDIV=200 :RDIV=2 :TDIV =1 :GREF=317
   'Most commonly used values assigned to keyboard inputable
   varibles, which can be changed later on.
104 REM INK= the number of ink used., ANGLE= angle of plane
        with horizontal (deg), LDIV= left channel mv/div,
        RDIV= right channel v/div, TDIV= time msec/div.
105 REM GREF= reference gap - between proximity probe tip
        and plate surface.
106 LTIME$=TIME$          'Note down the time in LTIME$.
107 CLS :GOSUB 1960       'CLear the Screen and go for data input
                           from keyboard.
109 LPRINT CHR$(12) : LPRINT 'Set on new page on printer.
110 BDNAME$="SCOPE12"                 'Lines 110 through 230
120 CALL IBFIND (BDNAME$,SCOPE%)      'communicates with the
125 IF SCOPE% < 0 THEN PRINT "ibfind error" 'oscilloscope,
130 CALL IBCLR (SCOPE%)               'acquires data from it,
131 WRT$="ascii; access l; wfmpre?"   'and stores on a disk
132 CALL IBWRT (SCOPE%,WRT$) 'placed in drive b: and
133 REM              under the names data.lft for left channel
134 RD$= SPACE$(66)           'and data.rgt for right channel.
135 CALL IBRD (SCOPE%,RD$)
136 L1$=MID$(RD$,22,4)
137 L1=VAL(L1$)
138 PRINT RD$,L1$,L1
140 WRT$="ascii; access l; curve?"
150 CALL IBWRT (SCOPE%,WRT$)
160 RD$= SPACE$(6)
170 CALL IBRD (SCOPE%,RD$)
175 FLNAME$="b:data.lft"
180 CALL IBRDF (SCOPE%, FLNAME$)
181 WRT$="ascii; access r; wfmpre?"
182 CALL IBWRT (SCOPE%,WRT$)
184 RD$= SPACE$(66)
185 CALL IBRD (SCOPE%,RD$)
186 L2$=MID$(RD$,22,4)
```

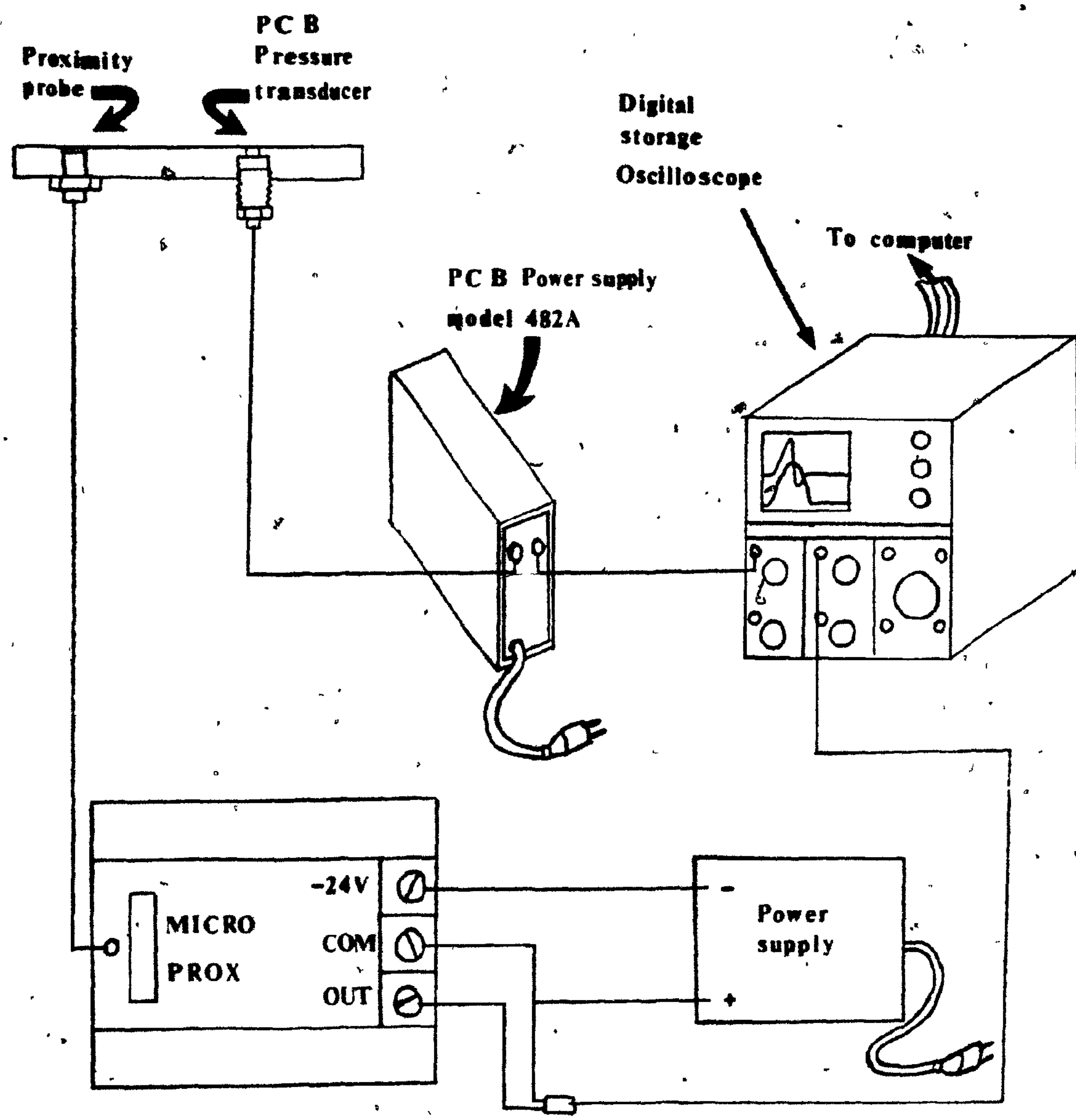
```
187 L2=VAL(L2$)
188 PRINT RD$,L2$,L2
190 WRT$="ascii;access r; curve?"
200 CALL IBWRT (SCOPE%,WRT$)
210 CALL IBRD (SCOPE%,RD$)
215 FLNAME$="b:data.rgt"
220 CALL IBRDF (SCOPE%, FLNAME$)
230 CALL IBLOC (SCOPE%)
240 OPEN "B:DATA.LFT" FOR INPUT AS #1  'Lines 240 through
245 REM                                 1140 reads data
250 OPEN "B:DATA.rgt" FOR INPUT AS #2  'written to file
255 REM                                 and find out required
260 FOR I=1  TO L1                     'values and uses those
280 FILEND1=EOF(1)                     'in the calculations.
300 IF FILEND1=-1 THEN LAST=I :GOTO 650
320 INPUT #1, A%
340 LEFT%(I)=A%                        'FILEND1 & FILEND2
341 REM                                 keeps track of end
342 IF I=1 THEN BIG%=A%  :SMALL%=A%    'of file, LAST points
343 REM                                 to the last data
344 IF A%>BIG% THEN BIG%=A%            'of the shortest file.
346 IF A%<SMALL% THEN SMALL%=A%          'BIG% and SMALL% is
350 REM                                   data points
420 FILEND2=EOF(2)                       'corrosponding to
430 REM                                   the +ve and -ve
440 IF FILEND2=-1 THEN LAST=I: GOTO 650  'pressure peaks.
460 INPUT #2, B%
480 RIGHT%(I)=B%                 'HI% and LO% is the data
482 IF I=1 THEN HI%=B% :LO%=B%   'point at the minimum and
484 IF B%>HI% THEN HI%=B% :PTR=I 'infinite gap between the
488 IF B%<LO% THEN LO%=B%        'plate and the cylinder.
500 REM                        PTR points to hi% in the array.
640 NEXT I
650 CLOSE
655 REM NULL% is the data that corrospond to zero pressure.
660 NULL%=LEFT%(980)
680 FOR I=981 TO 990 : NULL%=NULL%+LEFT%(I) :NEXT
700 NULL%=NULL%/11
840 OTHER%=RIGHT%(PTR+100)         'OTHER% is another point
860 MAXIMUM=(BIG%-NULL%)/100*LDIV  'on proximity curve at
870 REM                             one time division away,
880 MINIMUM=(NULL%-SMALL%)/100*LDIV 'used to calculate speed
890 REM                             of the cylinder.
900 PRESUR=MAXIMUM*.24855          'PRESUR is maximum
910 REM                            positive pressure.
920 TACK=MINIMUM*.24855            'TACK is maximum negative
930 REM                            pressure.
940 DEF FNGP(V)=195.6066-12.59922*V 'calibration function
950 REM                            for proximity.
960 CLOS=(HI%-LO%)/100*RDIV-21.66
980 GAP=FNGP(CLOS)
1000 FLTH=INT(GAP-GREF)        'FLTH is the film thickness.
1020 AN=(OTHER%-LO%)/100*RDIV-21.66
```

```
1040 CRVPT=FNGP(AN)  'CRVPT is cylinder-plate gap at another
                      point, used for speed calculation.
1060 T=TDIV/1000      'T is time between the two point.
1080 E=1-((CRVPT-GAP)/73500!)
1100 F=ATN(SQR(-E*E+1)/E)
1120 OMEGA=F/T       'OMEGA is angular speed of the cylinder.
1140 SPEED=OMEGA*.0735  'SPEED is peripheral speed of
1141 REM                 the cylinder
1142 REM Lines 1160 through 1540 plots the wave forms on
1144 REM the screen with the use of the computer graphics
1145 REM system and these wave forms are printed on
1146 REM the line-printer when lines 1570 to 1605 is
1148 REM executed after printing the results at line 1560.
1150 REM
1155 REM
1160 SCREEN 2:KEY OFF:CLS
1220 FOR I=1 TO 10:LINE (80,190-140/10.16*I)-
     (85,190-140/10.16*I):NEXT
1240 FOR I=1 TO 10:LINE (560,190-140/10.16*I)-
     (555,190-140/10.16*I):NEXT
1260 FOR I=1 TO 10:LINE (80+I*480/10.24,190)-
     (80+I*480/10.24,187):NEXT
1280 FOR I=1 TO 10: LINE (80+I*480/10.24,50)-
     (80+I*480/10.24,53):NEXT
1300 LINE (80,50)-(560,190),,B
1360 FOR I=1 TO 1000
1380 XX=80+((LEFT%(I)+512)/1024)*480:YY=50+(I/1016*140)
1440 PSET(XX,YY)
1460 NN=80+((RIGHT%(I)+512)/1024)*480: ZZ=50+(I/1016*140)
1520 PSET (NN,ZZ)
1540 NEXT I
1560 GOSUB 1660            'Print the results on the printer.
1570 DEF SEG = &HF000      'Lines 1570 to 1605 prints on the
1575 FOR Z = 0 TO 2        'line-printer, the waveforms
1580 READ J                'created on the screen.
1585 POKE Z,J
1590 NEXT Z
1595 DATA &HCD, &H05, &HCB
1597 RESTORE 1595
1600 SCREENPRINT = 0
1605 CALL SCREENPRINT
1610 STOP       'Stop until a function key is pressed
1615 REM         to CONTINUE for another experiment.
1625 GOTO 105   'Repeat the loop for another experiment.
1630 END
1640 REM
1645 REM The subroutine to print results on top of a paper.
1650 REM The wave forms plotted on the screen can be printed
1655 REM below the results on the same paper.
1657 REM
1660 LPRINT USING "& & & & & ### & ###";"Date",DATE$,"time",
                  LTIME$," Expt. No. ",EX," Ink No.",INK
1680 LPRINT USING "& ##.# & ####.## & ####.##";"Angle of
```

```
     Plane(deg.)",ANGLE," Maximum Pressure (psi.)",PRESUR,
     " Tack (psi.)",TACK
1700 LPRINT USING "& #### & ##.##";
     "Film Thickness (microns)",FLTH," Speed (m/sec)",SPEED
1721 LPRINT
1722 LPRINT USING "& ##.# & #### & ##.#";
     "scale := x-time msec/div",TDIV,"y-pressure mv/div",
     LDIV,"y-proximity v/div",RDIV
1740 RETURN
1800 REM
1805 REM  The subroutine to input values from the keyboard
1810 REM  for some variables which has been changed between
1815 REM  runs.
1820 REM
1960 IF GREF=0 THEN INPUT "input reference gap in microns";
     GREF
1980 PRINT "expt. no";EX
2000 INPUT "input new value ";EX
2020 PRINT "ink no."; INK
2040 INPUT "do you want to change ?"; Y$
2060 IF Y$="y" THEN INPUT "input new ink no.";INK
2080 PRINT "angle"; ANGLE
2100 INPUT "do you want to change?"; Y1$
2120 IF Y1$="y" THEN INPUT "input new angle (deg.)";ANGLE
2140 PRINT "left mv/div"; LDIV
2160 INPUT "do you want to change left mv/div?"; Y2$
2180 IF Y2$="y" THEN INPUT "input new left mv/div?";LDIV
2200 PRINT "right v/div";RDIV
2220 INPUT "do you want to change right v/div?";Y3$
2240 IF Y3$="y" THEN INPUT "input new right v/div?";RDIV
2260 PRINT "time msec/div"; TDIV
2280 INPUT "do you want to change time msec/div?"; Y4$
2300 IF Y4$="y" THEN INPUT "input new time msec/div";TDIV
2320 RETURN
```

APPENDIX E

ELECTRICAL CIRCUITS



Appendix F

MANOMETER CALIBRATION

Calibrate the manometer in the following way:

1. Attach a weight of 18.4 kg on the balance device E (Fig. 5-2) and make sure that the cords from the hook are running over the pulley J and that the weight has come to rest.

2. Switch on the current by means of the toggle switch on the front of the machine and start the test printing machine (about 300 revolutionsper minute).

3. Pump until a reading of 343 kPa (3.4 kgf/sq. cm) is obtained on the manometer, when the signal lamp on the left side of the press should flash. Slowly decrease the pressure in the pressure chamber F by means of the valve thereon until the signal lamp goes out.

4. Read the manometer. This reading indicates a force of

1.47 kN (147 kgf) between the cylinders A and B and a line pressure of 157 N/cm (15.7 kgf/cm) on the test printing press.