CORRELATION & STANDARDIZATION OF CHEMICAL, PHYSICAL & MICROSCOPICAL METHODS OF TESTING IRON & STEEL

THE CORRELATION AND STANDARDIZATION

of

CHEMICAL, PHYSICAL AND MICROSCOPICAL

METHODS OF TESTING IRON AND STEEL.

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The correlation and standardization of chemical, physical and microscopical methods of testing iron and steel.

This title covers so vast a field that volumes would be needed to set forth the present knowledge of the subject, and this thesis will be mostly confined to a description of the work done and results obtained, during the past year, by the writer, working under Dr.Stansfield in the Metallurgical Laboratory of McGill College.

The relation between the chemical composition and heat, or mechanical treatment on the one hand, and the microscopic structure on the other, is dealt with at some length in the description of the photomicrographs. The relation between the chemical composition and heat treatment on the one hand, and the mechanical properties on the other, was investigated with important results which are set forth in the account of the tests made on spring steel.

Metallography, or the study of metals and alloys by their structure, generally under the microscope, has, owing to its being the least familiar and perhaps the largest division of the subject, received the most attention. A fairly complete set of specimens, illustrating irons and steels of different compositions and different heat and mechanical treatment, has been polished, etched and photographed. A complete set of the photographs is on record in the Metallurgical Department, and may be referred to as an amplification of parts of this thesis. A set of lantern slides has also been prepared for the use of the staff of the Department.

Before giving the results of the work with the microscope, a brief account of the constitution of alloys in general, and the methods of examining them, may not be out of place.

DEFINITION: "A metallic alloy is a substance possessing the general physical properties of a metal, but consisting of two or more metals, or of metals with metalloids, in intimate mixture, solution or combination with one another, forming, when melted, a homogeneous fluid." This definition is very comprehensive and descriptive. A alloy must have the properties of a metal: thus, for example, pyrite is excluded from the class while white cast iron is admitted, though both are compounds of iron with a metalloid. It must be admitted, however, that there is a shading from alloys to non-alloys, just as there is from metals to non-metals; in the present case, for instance, it would probably be found that a mass of pure iron carbide is little more metallic than iron sulphide.

Intimate mixture: Some metals, for example lead and tin, are only very slightly soluble in one another when cold, and almost all possible alloys of them consist of a mechanical mixture of the eutectic, or alloy of lowest freezing point, with the excess metal, whichever it is. The frozen eutectic itself is a very intimate mixture in constant proportions--not necessarily atomic---of the constituent metals. See photograph 108.C.3.

Solution: In other cases, e.g. alloys of gold with silver,

the metals dissolve one another in all proportions when cold, and if quickly frozen, or very slowly cooled after solidification, are homogeneous when cold. There are, of course, intermediate cases in which the metals are soluble in one another to a limited extent; these will form solid solution or euctectiferous alloys according to whether or not this limit is exceeded. See photograph 116.1.

Compounds: In certain cases, a common example being the copper-zinc alloys, the metals form one or more definite, though feeble compounds, which in turn may or may not form a eutectic with the metal in excess over the percentage in the compound.

Homogeneous fluid: Molten zinc and molten lead might be stirred together just before freezing, and if quickly frozen, form a pseudo-alloy, but when melted their natural habit is to separate into layers, so the alloy is not a true one.

METHODS OF STUDY. The two important methods of studying the constitution of metals and alloys, granting their chemical composition already determined, are the making of cooling curves by means of a recording pyrometer, and the examination of properly prepared sections under the microscope.

The recording pyrometer in the Metallurgical Laboratory consists of a reflecting galvanometer with leads to a Platinum--Platinum.Rhodium thermocouple. The spot of light from the galvanometer moves along a scale, and the readings are generally observed

and noted, but a slit along the scale admits part of the light to a narrow closet, in which a holder carrying a photographic plate may be moved regularly in a vertical direction by means of a water-clock. Thus the horizontal position of the spot of light records the temperature, and the vertical position of the plate, that is of the spot on the plate, records the time. A few lines made on the plate when the thermocouple is at some known constant temperature, calibrate it and the temperature-time curve is complete.

Cooling curves made in this way of a solidifying alloy will show (1) when freezing begins, by recording an interruption in the loss of heat by radiation as the latent heat of fusion is given up. Secondly, if the temperature remains constant till freezing is complete, it is an indication that the composition remains constant, that is, that the metal is either pure metal or a eutectic alloy. Thirdly, if the temperature continues to fall, but more slowly, it indicates that the excess metal is freezing out, bringing the composition nearer to that of the eutectic alloy, and the period of constant temperature, when the eutectic is freezing will be indicated later. Fourthly, if the alloy is a solid solution, slowly freezing, the temperature will fall slightly and continuously during the freezing, as the crystals first separating out will be richer in the metal of higher melting point, because the force holding the metals in mutual solution is not strong enough to entirely over-

come the tendency of the metal of lower melting point to remain in the molten mother-metal, lowering its freezing point. Finally, if the alloy contains a compound the cooling curve will, in general, be like case three. For curves illustrating these cases see page

By making a series of cooling curves for alloys with varying proportions of (say) two metals, a composition-freezing point curve may be plotted, and will take one of the forms shown on page On such a diagram may also be plotted the loci of changes, e.g. molecular, taking place in the cooling solid alloy, and also the temperature-mutual solubility curve, which, it will be understood, determines whether or not a given alloy will be eutectiferous. This subject is dealt with in great detail by H.M.Howe, but so complex and unlimited is it, that even in his book, only the theory of binary alloys containing no chemical compounds is treated fully.

MICROSCOPIC EXAMINATION. For examination in this way a metallic specimen is prepared in the following manner.

If of soft material it should be cut with a hack-saw to about 1/2" square (or diam.) X 1/4" thick; if of hard material it will have to be chipped. A suitable face is made flat by pressing it on an emery wheel, or rubbing it on a file, care being taken when using the emery wheel not to heat the specimen if there is any chance that heating will change its constitution, and when using the file not to make the face convex. Care should also be taken not to bruise

the face that is to be polished when stamping identification marks on the opposite face. When a flat face has been secured, the coarse grooves are removed on a fine emery wheel or a very fine file, making the new scratches at right angles to the old and persisting till all traces of them are removed; this is important as they cannot be removed by the finer polishing except with a very great expense of time, and the convexing of the face. The fine emery wheel is succeeded by a canvas covered disc moistened with water and fine emery powder, then a disc moistened with water and washed tripoli powder, and finally a broadcloth disc moistened with water and washed jewelers' rouge. In every case the striations are made at right angles to the preceding, coarser ones. In the final polishing the specimen should be rotated, or even the rouge cloth may leave some fine striations. The polishing machines used for this work are illustrated on page 11.

The specimen is now ready for a preliminary examination in the microscope. If it shows any considerable scratching or pitting some of the latter stages of the polishing will have to be repeated, but if it is blank---smooth and bright---it is ready for etching. The appearance before etching should be noted: whether the metal is perfectly clean and apparently homogeneous, or whether it shows graphite, slag or sulphide, cracks or other imperfections.

To etch the specimen: It should be cleaned of grease if

necessary, by rinsing in alcohol, then it is dipped in the reagent for a few seconds, rinsed in running water, shaken, rinsed in two or three small quantities of pure alcohol dropped on it, and finally dried in a stream of warm air---such as rises from the arc light used for the microscope. The polished face of the specimen should never be touched by anything after polishing is complete. If it is touched with the fingers before being etched the greasy marks may make etching uneven, and if touched after etching, washing and drying are complete the moisture of the fingers may cause rust or tarnish after it is put away. Specimens prepared by the writer ten months ago, and used a good deal for demonstration, are almost as bright and clean as when first etched. The specimens should be put away with the polished face not touching anything; otherwise soft material and stains will receive scratches. A good plan is to handle them with forceps.

For iron and steel a 5% solution of nitric acid in alcohol was generally used. For quenched steels, a 5% solution of picric acid in alcohol gave good results; and to develop martensite, Osmond's polish attack---friction on a parchment pad moistened with a 2% solution of ammonium nitrate, was used. The depth of etching will depend on the specimen: when etching low-carbon steel, the amount that will develop the crystals of ferrite (pure iron) will make the carbon bearing constituent very dark, with indistinct structure. It is good

practice to etch lightly at first, examine in the microscope, and etch again if necessary.

When the specimen has been properly etched, it should be examined again in the microscope with a moderate magnification, noting variations in the general appearance from place to place, particularly towards the surface, if the section is one that cuts an original surface---this is where the necessity for keeping the face flat is perceived. The constituents should be tested for hardness by using a needle while observing through the microscope. The specimen should also be examined with higher magnification to develop secondary structure, and details of very fine-grained specimens.

A fairly selected area may now be photographed. The arrangement of the microscope-camera will be understood from the illustrations on page IIA. By using a glass slide engraved with lines 1/100 of a millimeter apart, a magnification table was prepared, giving the length between the specimen and the ground glass (which length is dependent only on the lenses used) necessary to obtain various even magnifications when using the different objectives and eyepieces. Photographs of fifteen diameters were made with a 3" objective; 75 diameters, 1/2" objective; 750 diameters, 1/8" objective and compensating eyepiece. One or two blue glass screens were always put between the illuminating arc and the microscope, when exposures were being made, and sometimes also a ground glass. For

direct observation two or three ground glasses were used. Exposure with low power is from five to twenty seconds, and with high power two to eight minutes.

In the marking of the photographs illustrating this thesis, and of the drop-tests to be described, the following system, devised for and used in the Metallurgical Laboratory, is retained.

Every distinct specimen receives a number, the first being 101. The letter following this number indicates the treatment of the specimen, thus:

C	A cross section.	R	Retreated.
L	A longitudinal section.	OQ	Oil-quenched.
D	A drop test.	WQ	Water-quenched.
B	a slow bending test.	T	A tensile test.

The number coming after the letter, or after the specimen number if there is no letter, is a specific or detail number referring to the manner in which the treatment was carried out. For example:

108.C.3. Specimen 108, a cross section, third photograph.

161.D.5.R.2. Material 161, a drop test, test bar 5, retreated twice. (Third time that the bar was tempered and tested.)

MICRO-CONSTITUENTS of iron and steel. The following definitions and description of the micro-constituents of iron and steel is given here in order that the description of the photographs may be understood from the start.

Ferrite. Pure or nearly pure iron; magnetic; soft, white grains, stained only faintly, even when etched till the crystalline

grains are distinct. Occurs in wrought iron, slowly cooled hypoeutectoid steel, gray and malleable cast iron.

Cementite. Carbide of iron, Fe_3C; magnetic; very hard and brittle; white, brilliant lustre, unattacked by any of the dilute etching reagents, and therefore always clean and free from indication of crystalline grains. Occurs in slowly cooled hypereutectoid steel, gray, mottled and white cast iron.

Pearlite. The eutectoid, or lowest transition-point alloy, of iron and carbon. Consists of alternate laminae of ferrite and cementite, and is intermediate in hardness. Etches dark very easily, presumably due to microscopic electrolytic action between the laminae. Occurs in all slowly cooled steel and cast iron.

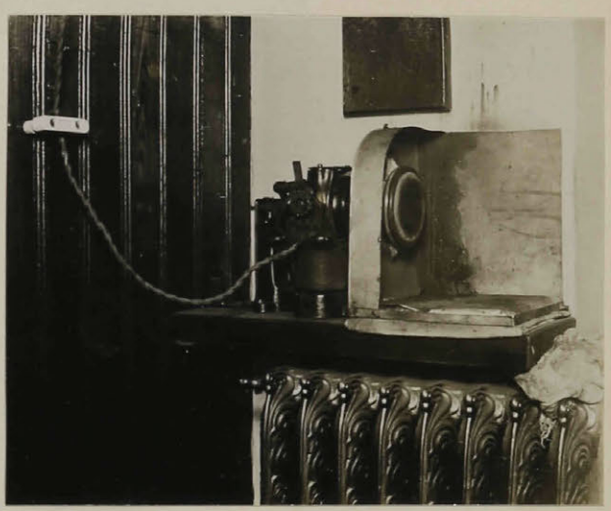
Sorbite, troostite, etc. These are transition products intermediate between martensite and pearlite. Their constitution is not very definite or well understood. See photograph 128. Occur in partially hardened and partially tempered steels.

Martensite. Supposed by some to be itself only a transition stage between austenite and pearlite. Properly prepared specimens show a network of intersecting needles. Is characteristic of hardened steels; is hard and brittle.

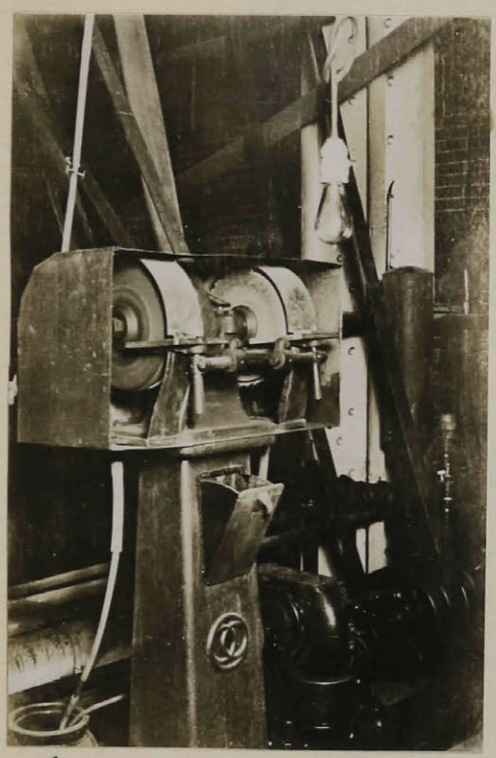
Austenite. The name given to the solid solution of carbon in gamma iron, gamma iron being the allotropic modification stable above 890° C.

Graphite. Pure, crystalline carbon; very soft; gray. Occurs as flakes in gray and mottled cast iron, and as foliated grains in malleable cast iron.

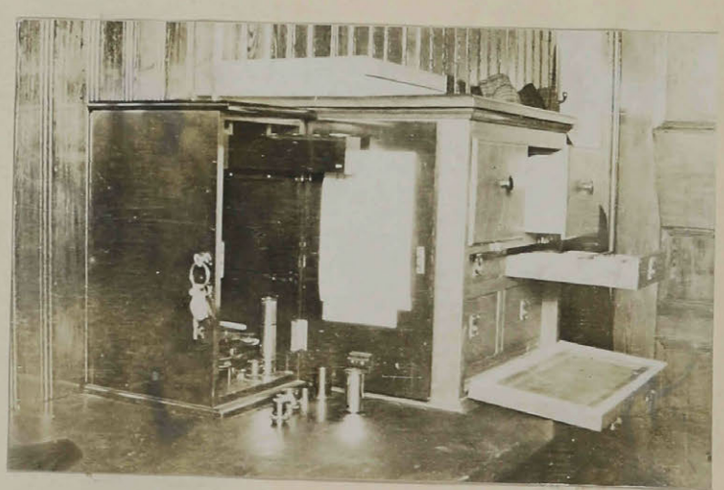
Slag. Mostly silicate of iron; dark gray or black, with a translucent appearance. Occurs in noticeable quantity only in wrought iron, as patches or streaks, according to whether the section is transverse or longitudinal.



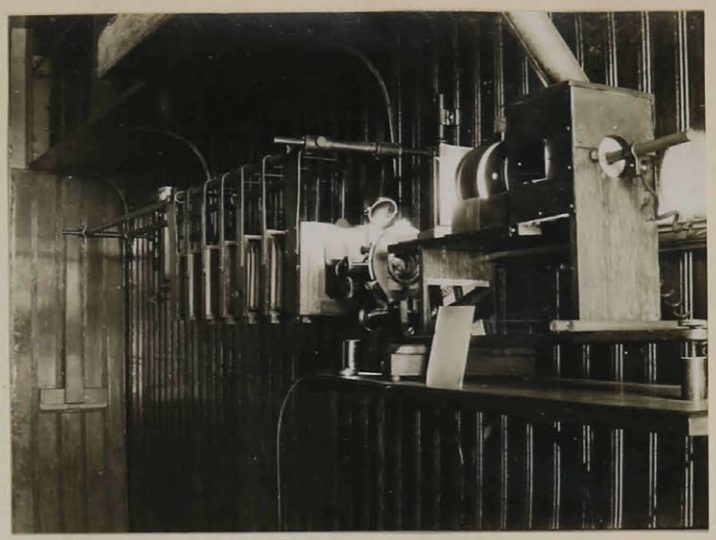
Fine rouge wheel in office



4 Disc Polishing Machine.

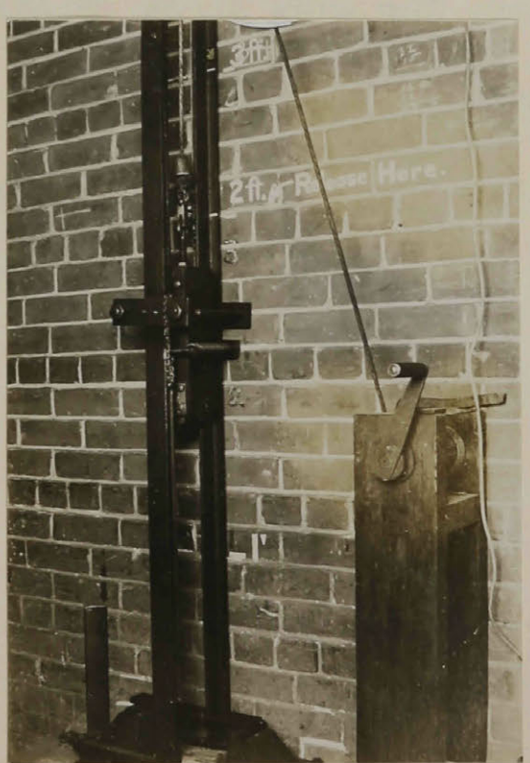


Microscope case, and specimen and negative file.

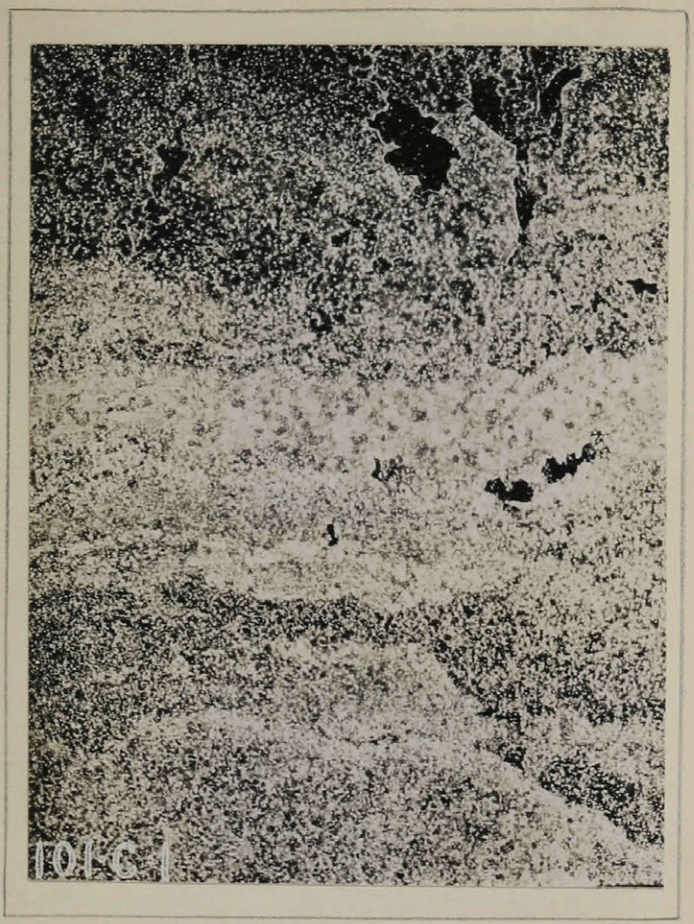


Taking a photomicrograph.

Ready for observing.



Ready for a 2-ft drop.



101.C.1. X 20. G.S.

Nitric acid. Oblique.

Wrought iron.

Cross section of a bar 1" square.

A good example of the practical use of metallography. Even to the naked eye the banded structure is plainly visible in the polished and etched specimen, showing that the bar was rolled from scrap of different kinds, which were not very well blended.

The photograph shows a band of clean ferrite, the crystals being distinct. Also bands of less pure ferrite, and some large and innumerable small patches of slag. In photograph 101.L.3 will be seen a zone of steel found in this specimen with higher magnification.

101.C.2. X 100. G.S.

Nitric acid. Vertical.

Cross section of a Wrought Iron bar, I" square.

Part of 101.C.1, enlarged. The part included is easily found in 101.C.1; it takes in the two smaller slag patches and the ferrite band.

This photograph shows more clearly the crystals of ferrite and patches of slag. It will be seen that the ferrite crystals show a tendency to be elongated in the direction of the length of the photograph. This was caused by finishing the rolling at too low a temperature, below the temperature at which Beta Iron changes to Alpha iron. Another point to notice is that the slag has a structure of its own, showing at least two constituents; with still higher magnification (500) this is found to be the case even in the very small strings of slag, of which so many are in this specimen.

101.L.3. X 100. G.S.

Nitric acid. Vertical.

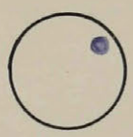
Longitudinal section of a Wrought Iron bar, 1" square; section made from the same slice of the bar as the cross section just described.

This photograph, like the last, shows ferrite and slag, the smaller patches of the latter being elongated and showing the direction of the rolling; in fact the ferrite also shows elongation. In addition to these two constituents, a third is seen, filling irregular spaces between the crystals of ferrite. This is pearlite, the carboniferous constituent of steel. If rolling had been finished at a higher temperature, the difference between the slag and the pearlite would have been greater, the slag being more elongated and the pearlite and ferrite not elongated at all.

102.C.1. X 75. G.S.

Nitric acid. Vertical.

Cross section of a Wrought Iron rod, 1/2" diameter.



Specimen shows a uniform mass of ferrite crystals without any general orientation---well rolled, genuine wrought iron.

The slag, of which there is a reasonable amount and no enormous patches, is distributed irregularly, some patches much larger than others. Compare with 105.C.1.

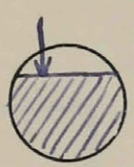
Note: Specimens 102 to 130, inclusive, except 116 and 117, were supplied with Sauveur & Whiting's Correspondence Course in Metallography. Loaned to this Laboratory by Dr. M.L.Hersey. They form a fairly complete set illustrating the iron-carbon series, including variations in composition and heat treatment.

Numbers 130 to 160 have mostly been allotted to a set of specimens partly duplicating this one and partly illustrating stages in commercial processes; sent to Dr.A.Stansfield by Prof.Wm.Campbell. This latter set has not yet been polished, etched and photographed.

103.L.1. X 75. G.S.

Nitric acid. Vertical.

Longitudinal section of a Wrought Iron rod, 1/2" diam.



Shows crystalline grains of ferrite and streaks of slag.

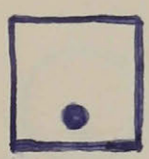
The orientation of the crystalline grains bears no relation to the direction of rolling; the majority of the grains do not vary greatly in size from the average, whereas the patches of slag vary in size from fine strings to pieces larger than any of grains of ferrite, and all of them are extremely drawn out by the rolling.

104. C. 1. X 75. G.S.

Nitric Acid. Vertical.

Steel, 0.10% Carbon, annealed.

Cross section of a 1/2" square bar.



Ferrite with intergranular pearlite.

The pearlite is fairly uniformly distributed, and takes up the spaces left to it by the crystals of ferrite, sometimes almost surrounding them.

105.C.1. X 75. G.S.

Nitric acid. Vertical.

Steel, 0.30% Carbon, annealed.

Cross section of a 1/2" round bar.

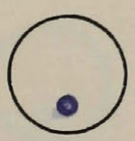
Like 104.C.1 but containing more pearlite in proportion to the increase of carbon.

106.C.1. X 75. G.S.

Nitric acid. Vertical.

Steel, 0.50% Carbon, annealed.

Cross section of a 1/2" round bar.



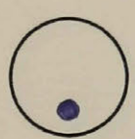
The structure of this specimen is apparently more different to that of the preceding than the difference of 0.20% in the carbon content would account for, but if the photograph is carefully examined it will be seen that the ferrite crystals intrude into the pearlite Indeed the ferrite has built up a network (of three dimensions, in the cooling steel) and the pearlite has segregated in the meshes. This is sufficient to account for the very different appearances. With 0.30% carbon the pearlite occupies the interstices in an aggregate of cubical--approaching spherical--grains, whereas with 0.50% carbon the free iron, ferrite, is small enough in amount to built up with its cubical grains, a more or less rectilineal framework in which the pearlite is contained.

107.C.1. X 75. G.S.

Nitric acid. Vertical.

Steel, 0.86% carbon, annealed.

Cross section of a 1/2" round bar.



Specimen has very nearly the eutectoid or pearlite percentage of carbon, and shows practically nothing else. Some small particles of slag appear in this and preceding specimens of steel.

It will be noted that the pearlite grains, if they may be so called, have no very definite boundaries, but that the mass is almost continuous. A steel containing only iron and carbon is strongest when the carbon is this percentage, more or less. See 107.C.2.

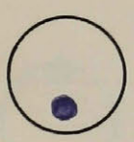
107.C.2. X 75. G.S.

Nitric Acid. Oblique.

Steel, 0.86% carbon, annealed.

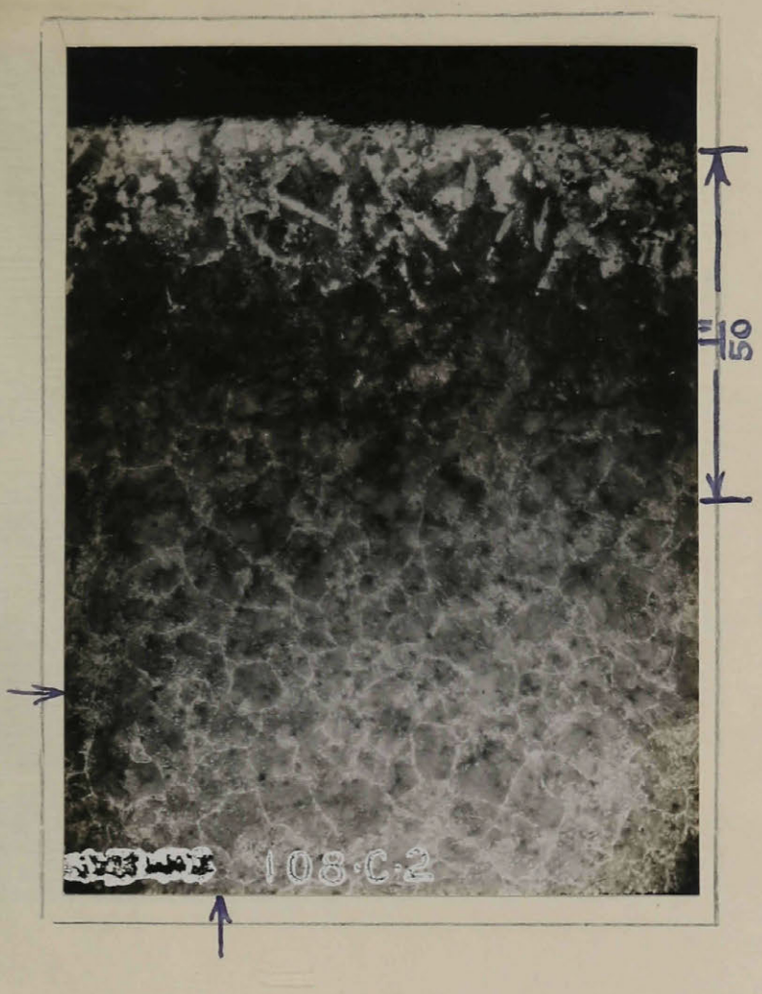
Cross section of a 1/2"

round bar.



This is identically the same area as shown in 107.C.1, but now the illumination is oblique.

The variation of light and shade is probably due to the varying inclination of the laminae of the pearlite from place to place, but, as in the last photograph, this variation is not regular or in sharply defined gradations.



108.C.2. X 75. G.S.

Nitric acid. Vertical.

Steel, 1.25% carbon, annealed. Cross section of a 1/2" round bar. Photograph taken so as to include the surface.

The percentage of carbon is now greater than is required to convert the ferrite entirely into pearlite, and shows as excess cementite in a network around the grains of pearlite. (Lower half of the photograph) This steel is said to be hypereutectoid, and is a tool-steel. The upper half of the photograph shows how the carbon has been illiminated by oxidation at the surface, and diffusion to the surface from the interior. From the hypereutectoid steel in the interior, through solid pearlite and hypoeutectoid steel, to pure ferrite at the surface, the altered thickness is about one-fiftieth of an inch. The same change was observed in all the preceding specimens, but only the complete scale as shown in this specimen was photographed. In some of the interior patches of pearlite in this ~~and the last~~ specimen the laminations of the pearlite may be seen.

Also 106.C.1.

108.C.3. X 750. G.S.

Nitric acid. Vertical.

Steel, 1.25% carbon, annealed.

Cross section of a 1/2" round bar.

Shows very well the curved and straight laminations of the pearlite, and that they do not cross one another. Shows also the intergranular veins of cementite.

109.1. X 75. G.S.

Nitric acid. Vertical.

Gray cast iron, #1 foundry.

0.1% to 0.3% combined carbon.

Specimen showed saw-cutting on five sides and a fracture on the sixth; the face opposite the fracture was photographed.

Shows bars (edges of flakes) of graphite, surrounded by ferrite, of which the crystals may be seen. Interior masses of pearlite and cementite. The cementite is recognized by its brilliant white lustre, unstained by the etching reagent or oxidation, by its lack of crystal dividing lines (because not etched) and, if in large enough patches, by its hardness. Also by its containing small rounded patches of pearlite, sometimes very small, numerous and arranged in lines. Note that the free carbon and the free iron are in contact, but that a dividing line of pearlite always lies between free iron-ferrite-and cementite.

110.1. X 75. G.S.

Nitric acid. Vertical.

Grey cast iron, #2 foundry.

0.3% to 0.5% combined carbon.

Specimen cut and prepared similarly to 109.

Structure is similar to that of 109.1, but shows more pearlite and cementite, and less ferrite and graphite. Also the bars of graphite are straight instead of curved as in 109.1, but this is probably not essential as both kinds occur in 111.1.

This specimen and photograph were much more successfully prepared than 109.1, and the relation of the constituents as described for the latter can better be followed out with this photograph.

111.1. X 75. G.S.

Nitric acid. Vertical.

Gray cast iron, #3 foundry.

0.5% to 0.8% combined carbon.

Specimen cut and prepared similarly to 109 and 110.

In this specimen so much of the total carbon is in the combined form that the network of graphite bars is very incomplete. Pearlite constitutes most of the mass.

112.1. X 15. G. S.

Nitric acid. Oblique.

Mottled cast iron.

Probably 2% combined carbon.

Specimen is a wedge-shaped flake, obtained by fracture.

This low-power photograph gives a general view to show the large spots or mottling. As the illumination is oblique, the lights and shades are reversed, the brilliant cementite groundmass appearing black because the light is totally reflected by it to the side of the microscope objective, and the pearlite appearing light colored by diffused light.

The photograph shows the even distribution of small patches of pearlite, somewhat arranged in rows, in the cementite, and the occurrence of large patches denser in pearlite, and, as will be seen, containing graphite.

The parts out of focus are irregularities not polished out.

112.2. X 75. G.S.

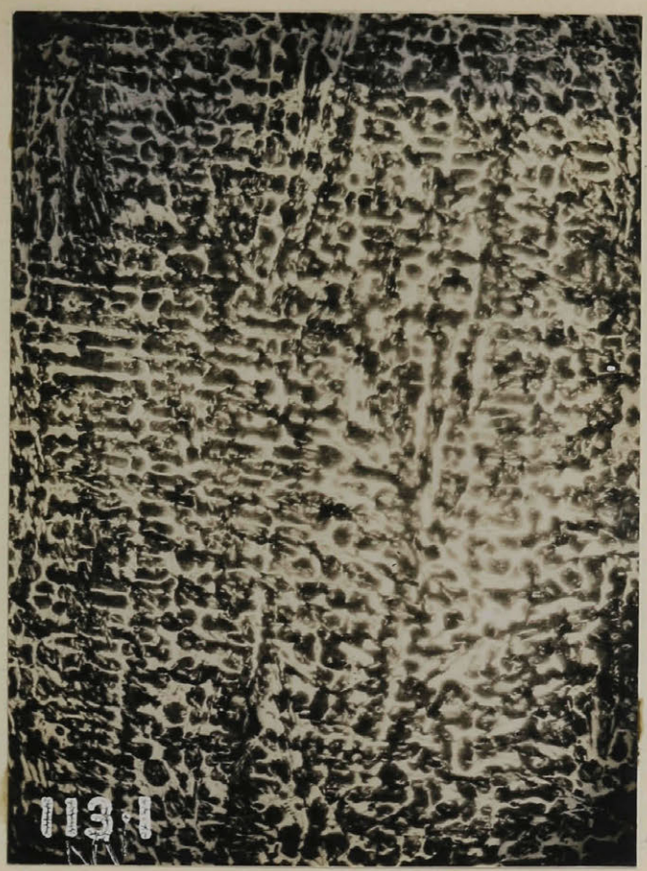
Nitric acid. Vertical.

Mottled cast iron.

Probably 2% combined carbon.

Specimen is a wedge-shaped flake obtained by fracture.

Photograph shows the details of the main mass, cementite containing rounded patches of pearlite. Also part of one of the large dark patches; in this the cementite has broken down into pearlite and graphite---fine-grained grey cast iron.

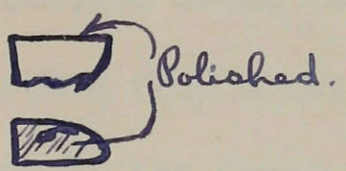


113.1. X 75. G. S.

Nitric acid. Vertical.

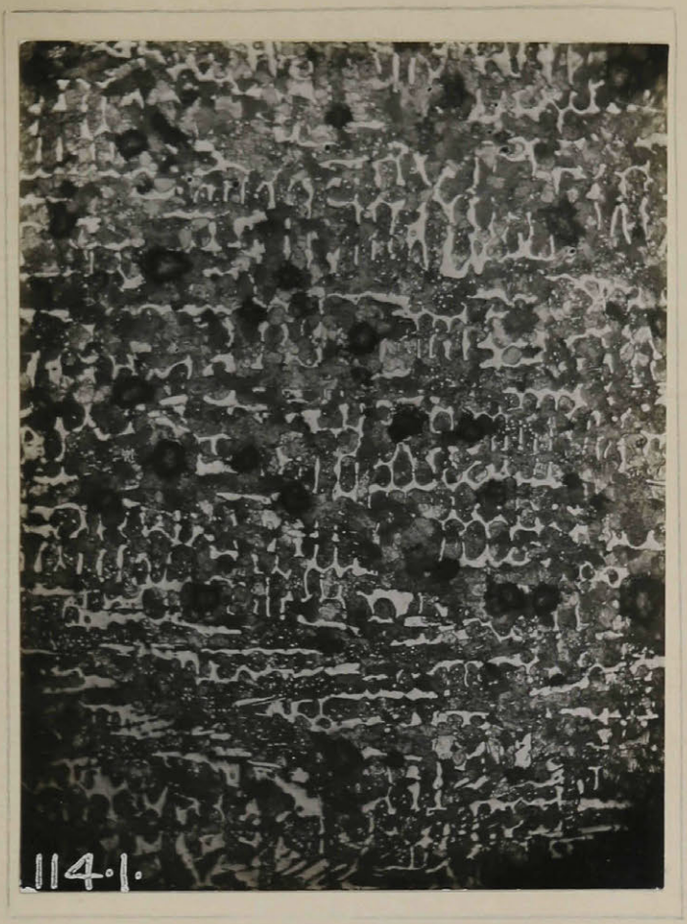
White cast iron.

Specimen is a quadrant of a "button".



Consists of cementite and pearlite, the latter in rounded patches arranged in lines. It resembles the mottled cast iron, but is finer grained and free from graphite. Compare with 112.1.

If the percentage of carbon is ~~not~~ less than 2.0% it could be called a high carbon tool steel, (if pure enough from P, S, etc.)



114.1. X 75. G.S.

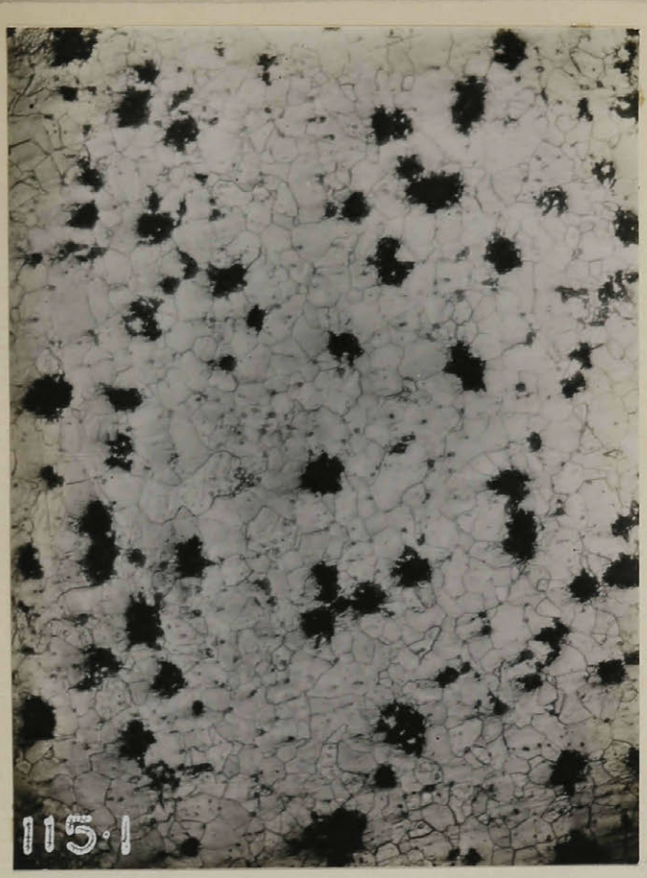
Nitric acid. Vertical.

Malleable cast iron, partly malleablized.

Specimen seems to have been broken from a thin cast plate; one of the fractures was polished.

Structure is very similar to that of white cast iron, from which the casting was made. There is less cementite than in the last specimen, and in its stead a number of spots of graphite, showing on the polished surface as graphite-lined pits.

According to A.Sauveur, the degree to which the dissociation of the cementite has taken place, at any stage of the malleablizing, increases from the interior to the surface. None of the specimens examined by the writer showed this, but it may be the case in very large castings, part of the heat being used up as it flows in, leaving the interior cooler than the outside. Considering the great time required, and the low heat of formation of cementite (Fe_3C = 8460) this does not seem very probable. Of course there is oxidation of the surface layers, removing the carbon entirely.



115.1. X 75. G.S.

Nitric acid. Vertical.

Malleable cast iron,

fully malleablized.

A piece of a thin casting.

A face perpindicular to cast surfaces was polished.

Clear, well crystallized ferrite, with patches of graphite. Pure ferrite at the surface, due to oxidation of the carbon.

Although containing about as much graphite as ordinary gray cast iron, this material is much stronger and comparatively ductile; This is due to the fact that the graphite is in compact masses instead large thin flakes, and entirely surrounded by a continuous mass of ferrite. Malleable cast iron is made from pure white cast iron by long heating, enabling the process which has started (in a bad way) in gray cast iron, namely the crystallizing out of the graphite, to become complete.

It will be noticed that the ferrite crystals are very distinct; This may be due to correct etching or to a certain looseness of the crystals; the material is certainly not so tough as wrought iron.

116.1. X 75. G.S.

Nitric acid. Vertical.

Cast manganese steel.

The section had to be made by using a strip of brass moistened with oil and emery in place of a hack-saw blade, which would not cut the specimen. It required about five hours to make a section about 1/2" X 3/4".

The main mass is of clear crystals, which, when properly etched, show three sets of hatching. Etching stains the surface all colours, mostly yellow, green and purple. Colours shade into one another, generally at the edges of crystals; stain is not removed by a needle scratch, but colours the groove. Scratching suggests a greasy toughness.

This shading of the colours is characteristic of alloys in which the metals form solid solutions. As such an alloy freezes, the mother-metal becomes richer in the metal of lower melting point, and the composition of the crystals varies from the outside towards the nucleus

Some slag, and a little eutectic, probably pearlite, was seen.

117.C.1. X 75. G.S.

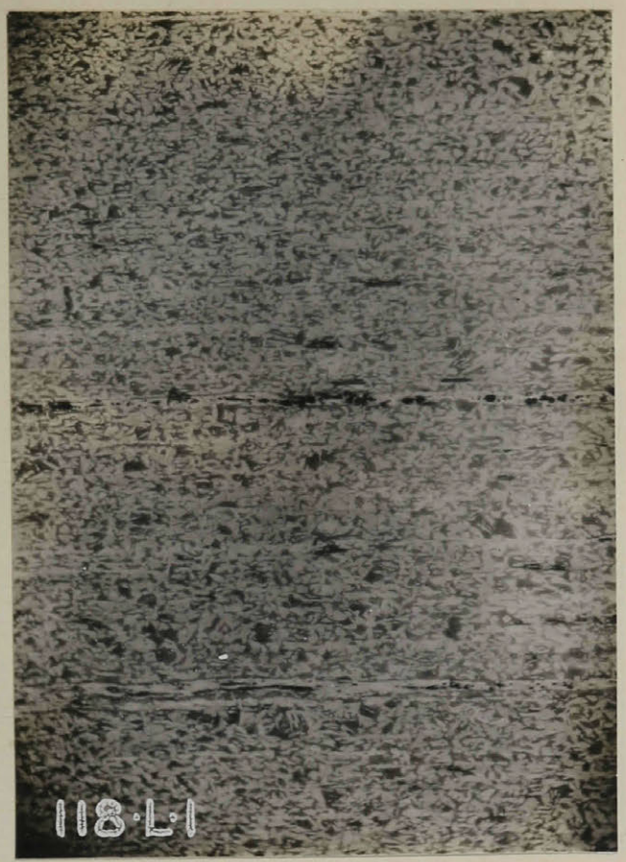
Nitric acid. Vertical.

Manganese steel; Allen's "Imperial" alloy.

Specimen is a 1" rolled bar; a cross sectional slice was cut with a hack-saw.

This specimen showed the same characteristics, and gave the same trouble in etching as the last, 116. It seemed purer and cleaner, but as the etching is deeper this would not seem to be the case from the photographs.

This rolled specimen is much finer grained than the cast steel.



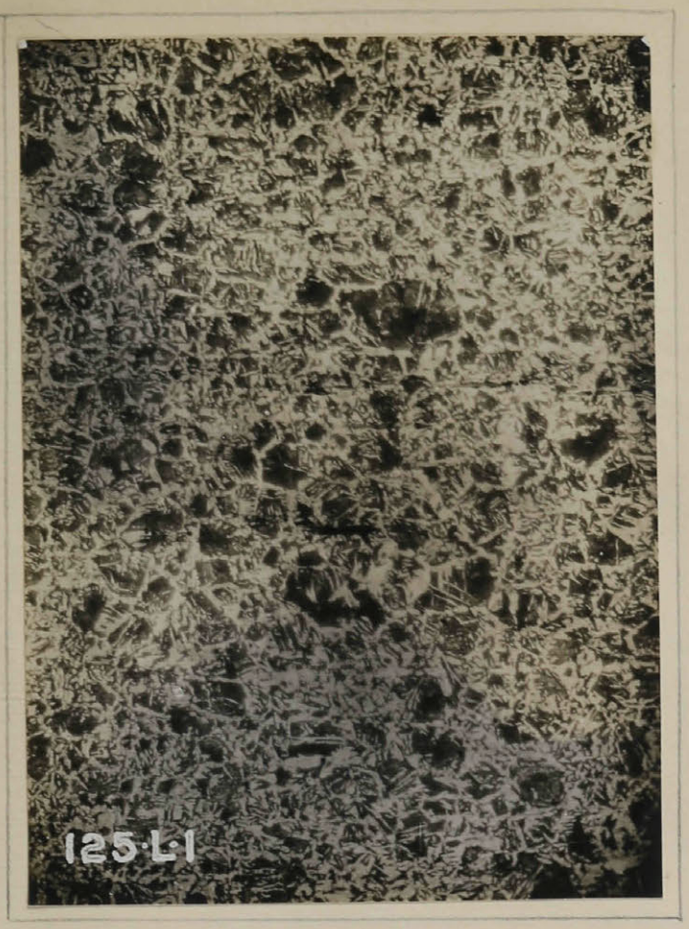
118.L.1. X 75. G.S.

Nitric acid. Vertical.

Steel, 0.30% carbon; drawn, cold worked.

A longitudinal section of a 9/32" rod.

Shows ferrite and pearlite in very fine broken crystals. Both constituents have been sharply elongated by the drawing, while the traces of slag have taken the form of lines of separated fragments. Compare with 103.L.1.



125.L.1. X 75. G.S.

Nitric acid. Vertical.

Steel, 0.30% carbon; drawn, and annealed.

Longitudinal section of a 9/32" rod.

Pearlite areas have a shattered appearance, due to ramifications of the ferrite network. Drawing (elongation) is shown by streaks of slag and ferrite, but the ferrite crystals themselves, and the patches of pearlite do not show it. Compare with 118.L.1; the grain of this specimen is much coarser, and consequently the ferrite and pearlite are less intimately mixed.

119.C.1 X 75. G.S.

Nitric acid. Vertical.

Steel, 0.30% carbon; forged, hot worked.

Cross section of a 1/2" square rod.

Extremely fine grained ferrite and pearlite; little or no oxidation of the carbon at the surface.

On account of the fineness of the grain, the temperature when forging ceased could not have been very high; a longitudinal section should have been made, to see if the specimen showed any elongation, to see, in fact, if the temperature was so low that the forging was practically "cold working".

126.C.1. X 75. G.S.

Nitric acid. Vertical.

Steel, 0.30% carbon; forged, and annealed.

Cross section of a 1/2" square bar.

Compare with 119.C.1. The increase in the size of the grain is of about the same order as that in specimens 118 and 125. Compare also with photograph 105.C.1; the only difference is that this bar 126, was worked at a lower temperature than 105---or was not annealed to so high a temperature.

For some reason not discovered the areas of pearlite seem to be arranged roughly in concentric circles. (Centre not in the photo.

120.1. X 75. G.S.

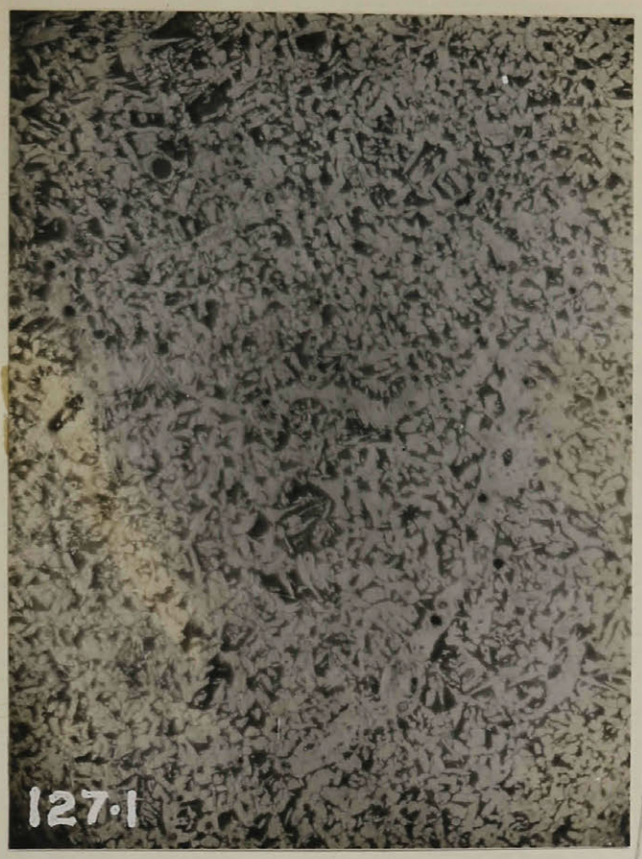
Nitric acid. Vertical.

Steel, 0.30% carbon; cast.

Specimen showed saw-cutting on all sides.

A very heterogeneous conglomerate of ferrite and pearlite. The pearlite is in large polygonal patches, boldly outlined with ferrite, and having an interior broken by crystals of ferrite.

These large patches of pearlite may be taken as marking out the original crystals of austenite formed at the high temperature of solidifying steel. As the large crystals of austenite cooled through the pearlite forming range, the excess ferrite was largely expelled to the wide borders, and also crystals of ferrite formed in the midst of the pearlite. The specks of impurity (slag or sulphide) are seen to lie along the centre of this border---they would mostly lie between the crystals of austenite.



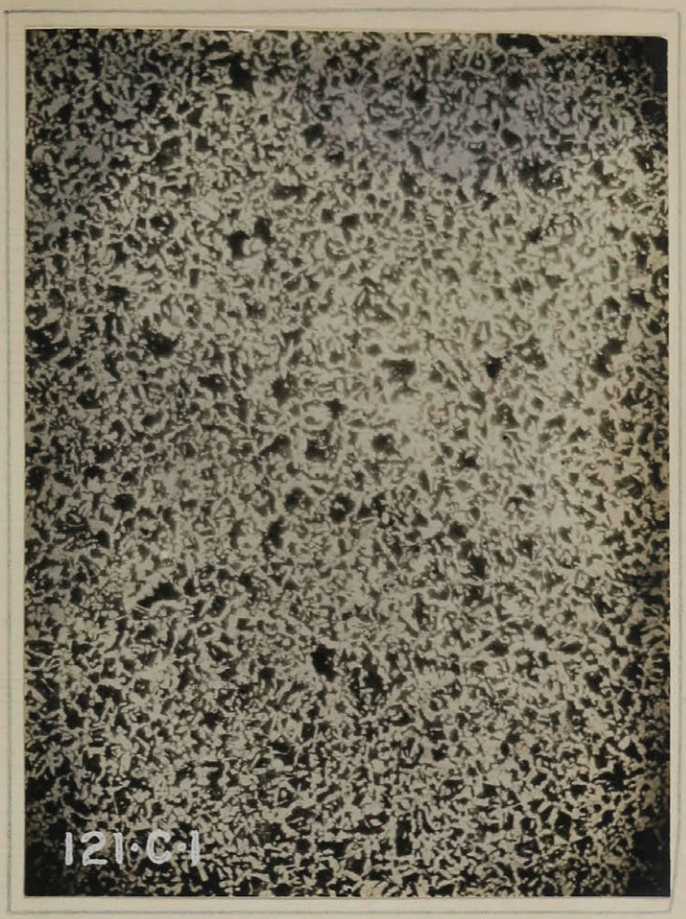
127.1. X 75. G.S.

Nitric acid. Vertical.

Steel, 0.30% carbon; cast and annealed.

Specimen showed saw-cutting on all sides.

The appearance shown in this photograph should have been expected after observing the drawn and forged steels before and after annealing. Most of the coarse structure of 120.1 has been changed to the fine structure of 105.C.1, the pearlite and ferrite being more uniformly distributed. Some of the broad ferrite borders may still be traced, and still contain the globules of impurities.



121.C.1. X 75. G.S.

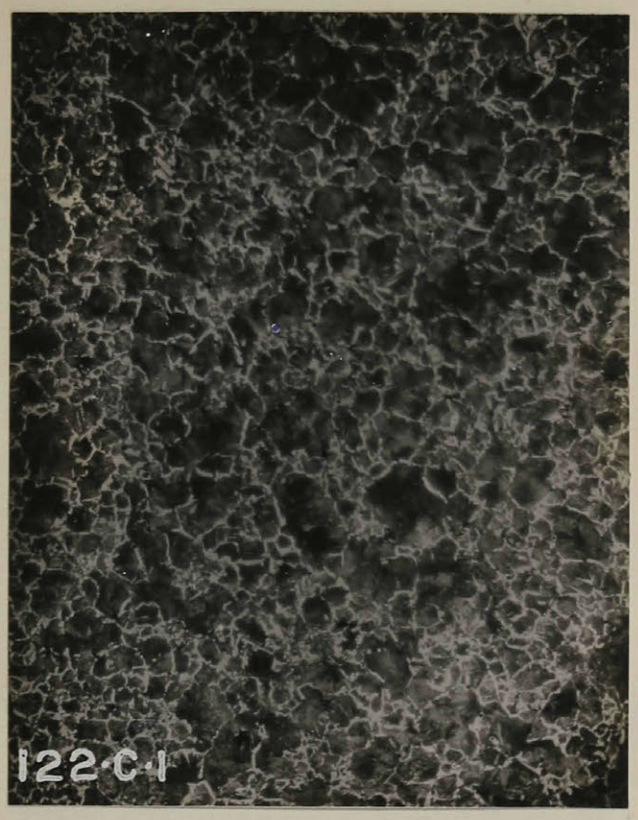
Nitric acid. Vertical.

Steel, 0.50% carbon; forged.

Cross section of a square $\frac{1}{2}$" bar.

Similar to 119.C.1, but coarser grained, and containing more pearlite. Apparently forging ceased when the metal was at a higher temperature, or else very little forging was done.

Contrast with 106.C.1. As these specimens were not cut from the same bar, it might be questioned whether the carbon contents were exactly the same, 0.50%.



122.C.1. X 75. G.S.

Nitric acid. Vertical.

Steel, 0.50% carbon; forged, heated to 800°C. and cooled in air.

Cross section of a 1/2" diam. round rod.

Compare with 121.C.1. The grain has increased considerably in size. Many of the pearlite patches have a rounded outline. The proportion of dark pearlite to light ferrite has increased and the pearlite patches show a tendency to shade off into the ferrite, the edges being lighter colored and not sharp. See also 123.C.1.

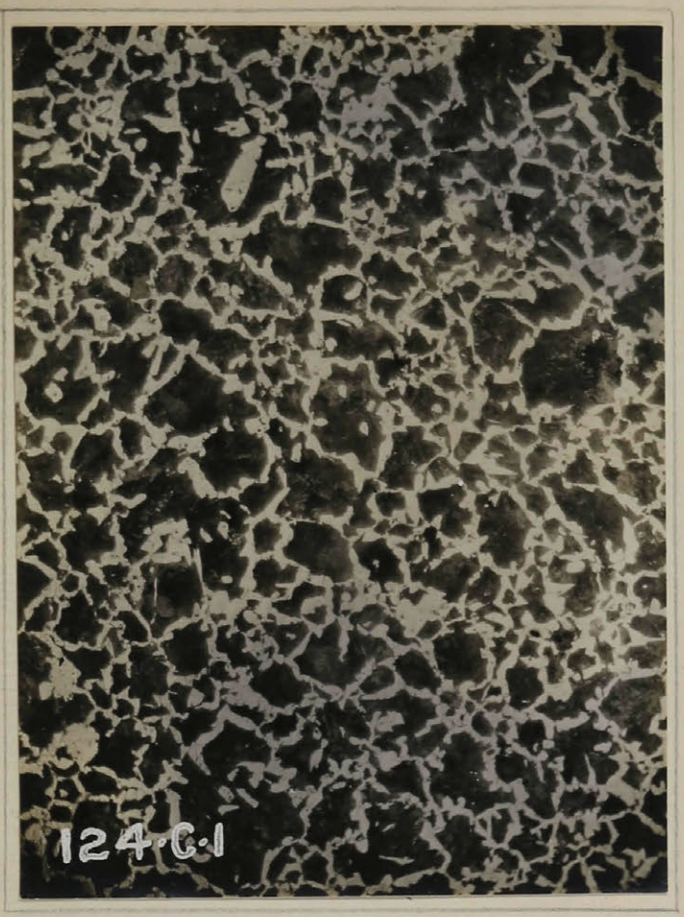
123.C.1. X 75. G.S.

Nitric acid. Vertical.

Steel, 0.50% carbon; forged, heated to 1000° C., and cooled in air.

Cross section of a 1/2" square bar.

Compare with 122.C.1. and 121.C.1. The grains are now very large and also very dark, only a thin network of ferrite running through the mass. At the high temperature it was heated to the steel consisted of large crystals of austenite, as described under 120.1. A small bar like this, cooling in air at room temperature, would cool fairly quickly, and, as shown by the photograph, only a part of the excess ferrite has had time to be expelled. As in the last photograph, the grains are lighter colored and indistinct at their borders, which is accounted for by their varying composition. Rigidity interceded when the ferrite was in the act of being expelled from the pearlite, or rather when the carbon was segregating to grains of pearlite composition. Compare with 116.1 and 117.C.1.



124.C.1. X 75. G.S.

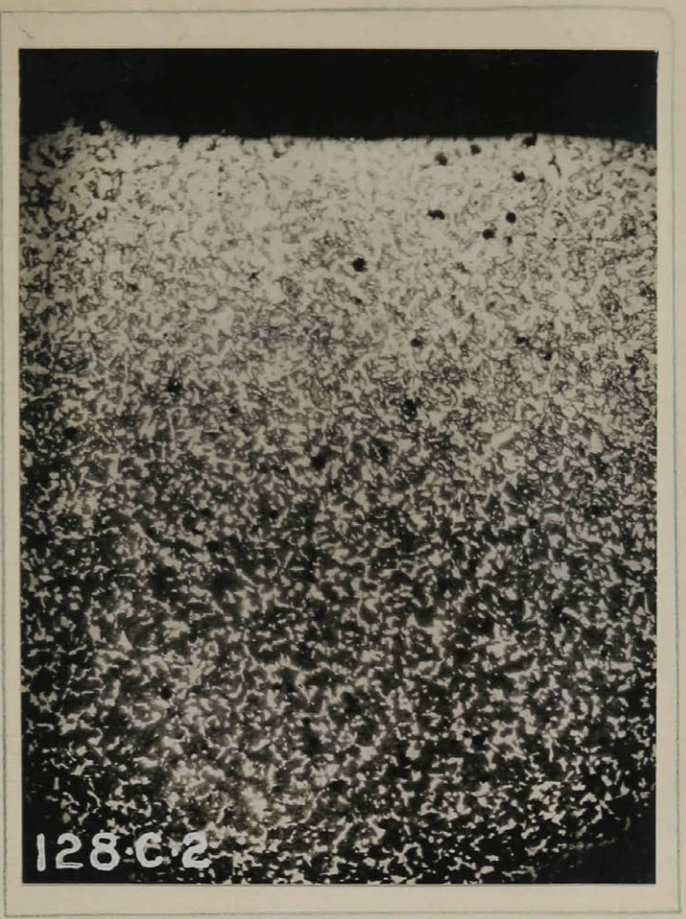
Nitric acid. Vertical.

Steel, 0.50% carbon; forged, heated to 1000° C., and cooled slowly in furnace.

Cross section of a 1/2" [illegible] round bar.

The appearance of this specimen is difficult to fully account for. The grains are much smaller than those in 123.C.1, and there is no trace of broken up larger grains as was the case in 120.1. The ratio of pearlite to ferrite is about the same as in 106.C.1. The sharpness of the grains, also, shows that the slow cooling has allowed the constituents to reach equilibrium.

Smaller size probably means that the true grains are subdivided by ferrite lines produced during slow cooling. There would be no broken up larger grains as the steel has been forged. A



128.C.2. X 75. G. S.

Picric acid. Vertical.

Steel, 0.50% carbon; heated to 800° C. and quenched in water.

Cross section of a 1/2" square bar.

According to A.Sauveur, this is a specimen of martensite and troostite. The photograph shows the characteristic pattern of troostite in the interior of the specimen---lower half of the photo. The upper half of the photograph shows, apparently, the decarbonization of the dark constituent at the surface by the air.

This photograph should be compared with 121.C.1. The constituents are very uniformly mixed, and in a way to produce a different pattern to that in slowly cooled steel of the same composition.

With higher magnification the dark constituent is seen to have a mottled, not a ribbed, surface. See 128.C.3.

Both constituents are fairly soft, and as martensite is hard, it would seem that this specimen had been quenched at too low a temp. On the other hand the different constituents are sharply separated, which is supposed to be the relation of troostite and martensite.

128.C.3. X 750. G.S.

Picric acid. Vertical.

Steel, 0.50% carbon; heated to 800° C., and quenched in water.

Cross section of a 1/2" square bar.

This high-power photograph shows the pattern of troostite, and the mottled, but not laminated, nature of the dark constituent. The clean separation of the dark and light constituents, as mentioned under 128.C.2, is clearly seen here.

The whole question of the real nature---chemical and microstructural---of steel that has been hardened and tempered, partly hardened, or fully hardened, is in a very indefinite condition. No one man seems to have worked on the problem long enough to get conclusive results, and several different opinions and theories, and many names for materials that shade into one another, make it impossible to properly discuss the constitution of such a specimen as 128, particularly as it was not prepared by the writer.

129.C.1. X 75. G.S.

Friction on parchment moistened with ammonium nitrate.

Vertical.

Steel, 0.50% carbon; heated to 850° C., and quenched in water.

Cross section of a 1/2" square bar.

This specimen shows all the characteristics attributed to martensite. It is very hard and brittle; difficult to polish and etch. The photograph shows a uniform field, lacking definite macrostructure, (in the same sense as did 107.C.1) but showing, even with this low power, a speckled or acicular microstructure.

129.C.2. X 750. G.S.

Friction on parchment moistened with ammonium nitrate.

Vertical.

Steel, 0.50% carbon; heated to 850° C., and quenched in water.

Cross section of a 1/2" square bar.

This photograph shows fairly well the intersecting needles of martensite. It should be compared with 108.C.3. The laminae of pearlite are much more distinct, being of different materials, and do not cross.

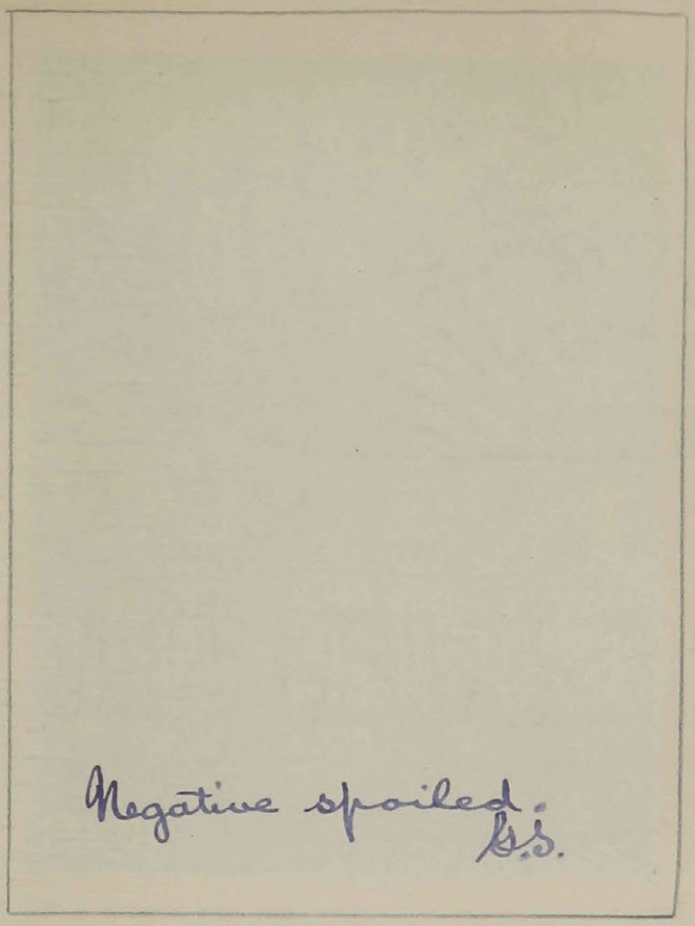
130.C.1. X 75. G.S.

Picric acid. Vertical.

Steel, 0.50% carbon; heated to 1000° C., quenched in water, reheated to 600° C., and quenched.

Cross section of a 1/2" square bar.

This is a specimen of "double-quenched" steel. The heat treatment is supposed to make it very strong. It will be seen to be very fine grained and uniform. The material is soft; it is probably one of the transition products in the decomposition of austensite and martensite to pearlite and excess ferrite. It was noticed that the change caused by oxidation in the surface layers of this specimen was somewhat similar to that observed in specimen 128. The general appearance of the specimen, as shown by this photograph may also be compared to that of 131.OQ.1, which will be described presently.



130.C.2. X 750. G.S.

Picric acid. Vertical.

Steel, 0.50% carbon; heated to 1000° C., quenched in water, reheated to 600° C., and quenched.

Cross section of a 1/2" square bar.

This photograph shows in more detail the constitution of specimen 130. It will be noticed that the dark constituent is granular rather than lamellar---"granular pearlite" perhaps. Both constituents are soft.

131.0Q.1. X 75. G.S.

Picric acid. Vertical.

Steel, 0.705% carbon; heated to about 1000° C., and quench-in heavy oil at ordinary temperature.

A cross sectional slice was cut 2 1/2" from the end of a test bar 7/8" square X 12" long, hardened as described above.

This test bar proved to be much stiffer than a similar one cut from the untreated bar of rolled machinery steel, and yet just about as ductile---not at all brittle in the drop test machine. The material is much harder than the untreated, but is easily scratched by a needle.

The photograph shows a remarkable radiated fine-grained structure. It may be compared with 107.C.2, but it must be remembered that 107.C.2 was taken with oblique light while this one was taken with vertical light; the compositionsof the two specimens are not very different, but the heat treatment is extremely different.

131.0Q.2. X 750. G.S.

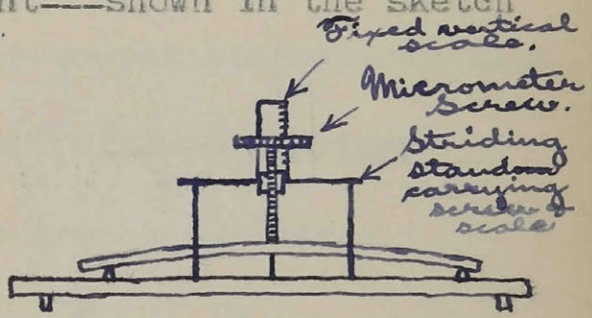
Picric acid. Vertical.

Steel, 0.705% carbon; heated to about 1000° C., and quenched in heavy oil at ordinary temperature.

A cross sectional slice was cut 2 1/2" from the end of a test bar 7/8" square X 12" long, hardened as described above.

Shows well the radiated grains described under 131.0Q.1. The dark constituent is laminated like pearlite but much more finely, and graduates gently into the light constituent; as a guess, it might be called sorbite.

MECHANICAL TESTING. The only method of mechanical testing used in the Metallurgical Laboratory is that of the drop test machine, the particular machine installed being on a small scale that made first cost low, and operation by hand easy for one man. The tup weighs 37.5 lbs., and has a maximum drop of fifteen feet. Bars from 3" to 18" in length may be tested. On hoisting, the tup is automatically released from the cord when it reaches the required height, drops on the bar, rebounds, and is caught at the top of the rebound. Since the rebound recording device has been improved, the machine has worked very satisfactorily, but this measurement is not a very accurate one, chiefly owing to friction. The permanent set given to the bar is measured by an instrument---shown in the sketch ---which reads to thousandths of an inch.



The total movement of the centre of the bar when struck is measured by the amount that a nail, just touching the bottom of the bar, is driven into a block of wood; it is not a reliable measurement because the bar, springing up when it straightens, often falls back on the nail, but the total movement is shown on some of the drop test curves to give an idea of what it amounted to, and a calculation of the skin stress, on the basis of the total movement with no permanent set is given on p.62.

The great advantage of a drop testing over a tensile testing machine is that a very small machine can do very severe work on

the test bars, that is, it can handle very large bars for its size, cost, and ease of manipulation. It was proposed to develop a method of testing rails by using cross-sectional slices, about 1" thick, of the rail, testing them across the flange and across the web. A stock of such slices is on hand, but on account of extensive tests on locomotive spring steels, the results of which were more urgently required, the work of standardizing the drop test machine with the rail sections has not yet been started.

SPRING STEELS. The experiments now to be described were intended at first to determine the best heat treatment for "Special Spring Steel", manufactured by Steel, Peech and Tozer, Ltd., of Sheffield, and used by the Can. Pac. Ry. for making locomotive springs. Later on the tests developed into a comparison between this steel and the steel known as Pennsylvania Analysis, of American manufacture. The analyses of the two steels are as follows:

	Our No.	C.	Mn.	S.	P.
English	160	0.64%	1.21%	.045%	.046%
American	161	0.96	0.38	.031	.033

It will be seen that there is quite a radical difference in the relation between carbon and manganese in the two steels, and also that the American steel is considerably lower in both sulphur and phosphorus.

A good many of the American steel bars were about 2.34" wide X .50" as compared with 1.64" wide X .48" for the English steel, so the standard set of seven drops used from the first for the narrow

bars, was changed from 1,1,2,2,3,3 & 6 ft. to 1.48, 1.48, 2.95, 2.95, 4.43, 4.43 & 8.85 ft. for bars 2.34" X .50" in section, and to 1.05, 1.05, 2.10, 2.10, 3.15, 3.15 & 6.30 ft. for bars planed to 1.64" X .50" section. All bars were tested on 11" centres. In this way all bars were treated, as nearly as possible, alike, so that if of exactly the same material, the work done on them would be the same, and so in plotting the results of the tests, the drops of whatever height, were always plotted as though of the original heights given. The horizontal scale of the curves shows the total drop in feet, and the distance between any critical point and the preceding one shows the height of the drop represented by that point. The vertical scale shows permanent set in inches, and the rebound in percentage of the drop. Of course the curve between critical points has no meaning, and is merely to assist the eye; when it ends at a critical point, the testing ceased there with the bar unbroken; breakage is indicated by a horizontal line to the ordinate representing the drop that broke the bar, then a short, heavy, vertical line.

These curves tell at a glance the effects produced in the bar during testing, and would admit of a great amount of discussion, sheet by sheet, but some general conclusions are all that space will allow. Before taking up these, an account of the heat treatment will be given to make the results more intelligible.

HEAT TREATMENT. As preliminaries, the platinum—platinum. rhodium thermocouple and reflecting galvanometer with no extra re-

sistance in the circuit were calibrated by taking cooling curves of aluminium and zinc, and with the readings for their freezing points of known temperature, and the zero reading of the instrument (taken when the thermocouple and cold junction were at equal temperatures, or cut off from the galvanometer) plotting a calibration curve. Cooling curves of the two spring steels were also taken, the thermocouple being plugged in a drill-hole in a short piece of bar, which was heated in a graphite crucible. The transformation point for steel 161 is 690° C. which agrees with Roberts-Austen's diagram. The same point for steel 160 is 680° C., probably lowered by the comparatively large amount of manganese, as a sufficient amount of manganese will lower it below ordinary room temperature. A heating curve taken for steel 160 shows the change point about 30° higher. than in the cooling curve.

The temperature of the furnace, when heating for quenching or tempering, was regulated by a nickel—iron pyrometer with station type millivolt meter. The maximum temperature was probably not more than 1000° C. (about 26 m.v.), and when tempering was about 600° C.

The bars to be hardened were fitted with a loop of wire and placed on edge, one at a time, in the furnace, which was a Muffle Furnace No.5, as made by the American Gas Furnace Co., and which was already hot. The bars heat to what is thought to be the correct temperature in about ten minutes, and are then removed and placed

across the Pt—Pt.Rd thermocouple, lying ready on a pad of asbestos board. The maximum reading of the pyrometer is noted, and when the spot of light retreats to the correct reading, previously decided upon, the bar is seized by the wire loop and plunged into the quenching oil, and moved in it till cool. Five gallons of "straw seal"oil, such as is used at the Angus Shops of the Can. Pac. Ry., is contained in a galvanized garbage barrel, having another about 4" greater in diameter, outside it, with water between. Cold water is run in after each quenching till the temperature is again correct. When used in the way described, the thermocouple gives the recalescence point (see page 65) about 10° or 15° too low. Magnetism begins to return at the end of the bar when the pyrometer, at the middle, indicates about 735° with steel 160, and 755° with steel 161. See "Report on Spring-making at the Angus Shops", page 125.

The hardened bars were tempered as follows: Two bars, with the thermocouple between them, and protected except at the junction, by being in the fold of a sheet of mica, were placed in an iron pipe (2" diam. for narrow bars, and 3" diam. for wide) in the gas furnace, now hardly a dull red heat. In this way they heat up to the required temperature in about twelve minutes, and are then immediately dumped out of the pipe and allowed to cool in air.

From the two sets of drop test curves the following results

and conclusions have been drawn. Without going into the details of the calculations, it may be said that towards the completion of the tests, averages were taken and it was found that a permanent set after the 6-ft. drop of 0.156" for steel 160 may be fairly compared with a corresponding set of 0.135" for steel 161; and breakage[a] of test bars of steel 160 of 45.5% with a breakage of 14.3% for steel 161. In the case of the only two bars of steel 161 that broke, they only broke under the 6-ft. drop, whereas bars of steel 160 sometimes broke under a 2-ft. drop, and many that broke were expected to be first-class. After the standard set of seven drops had been given, a number of bars remaining unbroken were subjected to severer testing, as follows: On steel 160, three additional drops of 6 ft., and three of 9 ft.; on steel 161, three additional drops of 8.85 ft., and three of 13.28 ft. The second of these sets of drops is fairly accurately equivalent to the first, considering the sizes of the bars. All the bars of steel 161 stood all the extra blows well; Nos.161.D.1, 2, 4, and 6.R. All the bars of steel 160 broke, thus: 160.D.21, 2nd blow or extra set; 23, 2nd blow; 6.R.2, 5th blow; and 8.R.2, 1st blow.

On the whole there is no doubt that steel 161 is more reliable than steel 160. Test bars of steel 161 were tempered to about the same degree of elasticity as the good bars of steel 160, and proobved to be far tougher under severe testing. Again a very considerable range in the temperature of the bars when quenched,

of the quenching oil, and of the temperature to which the bars were tempered, gave uniformly good results with steel 161, whereas with steel 160 the limits are so narrow that to make a bar as elastic as the average bar of steel 161, is to run the risk of making it dangerously brittle. ¶ Another definite result is that it may not be hoped ever to do without tempering after hardening. Some bars hardened at a low temperature in hot oil were fairly strong, but showed the peculiarity of being soft under the initial small drops, and brittle under the subsequent higher drops; in fact the most brittle bars were quite soft under the first small drops. This is explained by assuming that the quenching produces a degree of looseness among the hard grains of the surface layers, while the interior of the bar is of the right hardness, the looseness being due to either the sudden initial shrinkage, or perhaps an actual difference in specific gravity between the different allotropic modifications of iron, for, of course, more of the surface layers are retained in the beta or gamma states than the interior layers. Subsequent tempering partially softens and expands the outer layers, restoring the cohesion of the metal, and if the layers near the neutral axis are too soft it is not important.

METHODS USED AT THE ANGUS SHOPS. The following account of the making of locomotive springs at the Angus shops may prove interesting, and will introduce the report which was made on this

department, and a copy of which is included in this thesis.

The plates, roughly cut to length, are heated in the middle by an oil flame, and a centering bead is punched from the side to be concave. Then the ends are heated and sheared to exact length, slotted, trimmed, etc. Formerly the ends were thinned down, but now the plates are left thick to the end, and instead have the corners taken off; from the point of view of heat treatment, this is a great improvement. To be cambered, the plates are heated to perhaps 900° C. in an oil furnace, and fitted by hand to the next larger plate, already bent and tempered. and sprung a little to give the new-shorter-plate more curvature. After cooling a little, the plate is quenched in straw seal oil, the temperature being guessed at. The hardened plate is tempered by being replaced in the same heating furnace till the oil is burnt off; the degree to which this is done also has to be estimated by eye. The smallest plates of the spring are removed from the oil while still dull red, so that the oil "flashes" and the plate is so soft that it does not need to be tempered. The tempered plates are then again fitted, and any twist or misfit taken out of them while at the tempering temperature by blows on the right points. The plates of a spring are allowed to become cold before being tied together by the buckle.

Putting on the buckle. The several plates are placed in position on a table, and squeezed together at the centre by a vise.

Then table, vise and spring are turned to a vertical position, and the buckle is slipped on at a white heat; sometimes it has to be hammered on and sometimes it is quite loose. Then the vise is released and the buckle is squeezed in both directions in a hydraulic press, at first alternately and then in both directions at once. Then the spring is removed from the press and the buckle is partially quenched with water. The buckle is of mild steel (0.19% to 0.20% carbon) forged from a bar and welded.

There are six furnaces (built in one), and six quenching tanks, one man and his helper working at each tank. The tanks hold about 200 gallons of straw seal oil, costing 45¢ per gallon, the temperature of which varies from room temperature to 75° C., and sometimes up to 115° C., with an average of about 50° C. The oil is very well stirred by a number of streams of air rising from the bottom along the centre; and an outer tank containing water, which is renewed when it becomes too warm, serves to keep the temperature down. The men are paid by the number of spring-plates tempered, and make complete springs, rather than plates of a few sizes only.

SKIN STRESSES in spring steel, calculated on the basis of the maximum deflection with no permanent set.

Energy in tup = 37.5# X 1.02' = 38.2 ft-lbs.

Equals work done on bar = (0.22"÷12) X (W÷2) = W0.009175 ft-lbs.

Whence W, the maximum force on bar, = 4170 lbs.

The neglecting of the dead weight of the tup, in producing bending, tends to offset the neglecting of friction and impact, and the net effect of these factors is less than the error in measuring total movement, and less than variation in the bars.

Taking moments:

$$M = \frac{If}{y} = \frac{B.D^3}{12} \text{ X } f \text{ X } \frac{2}{D} = \frac{1.6 \text{ X } .48 \text{ X } .48 \text{ X } f}{6} = 0.0615.f \text{ in-lbs.}$$

Equals $\frac{W}{2}$ X $\frac{L}{2}$ = 2085# X 5.5" = 11,450 in-lbs.

Whence f, the maximum fibre stress, = 186,000 lbs. per sq.in.

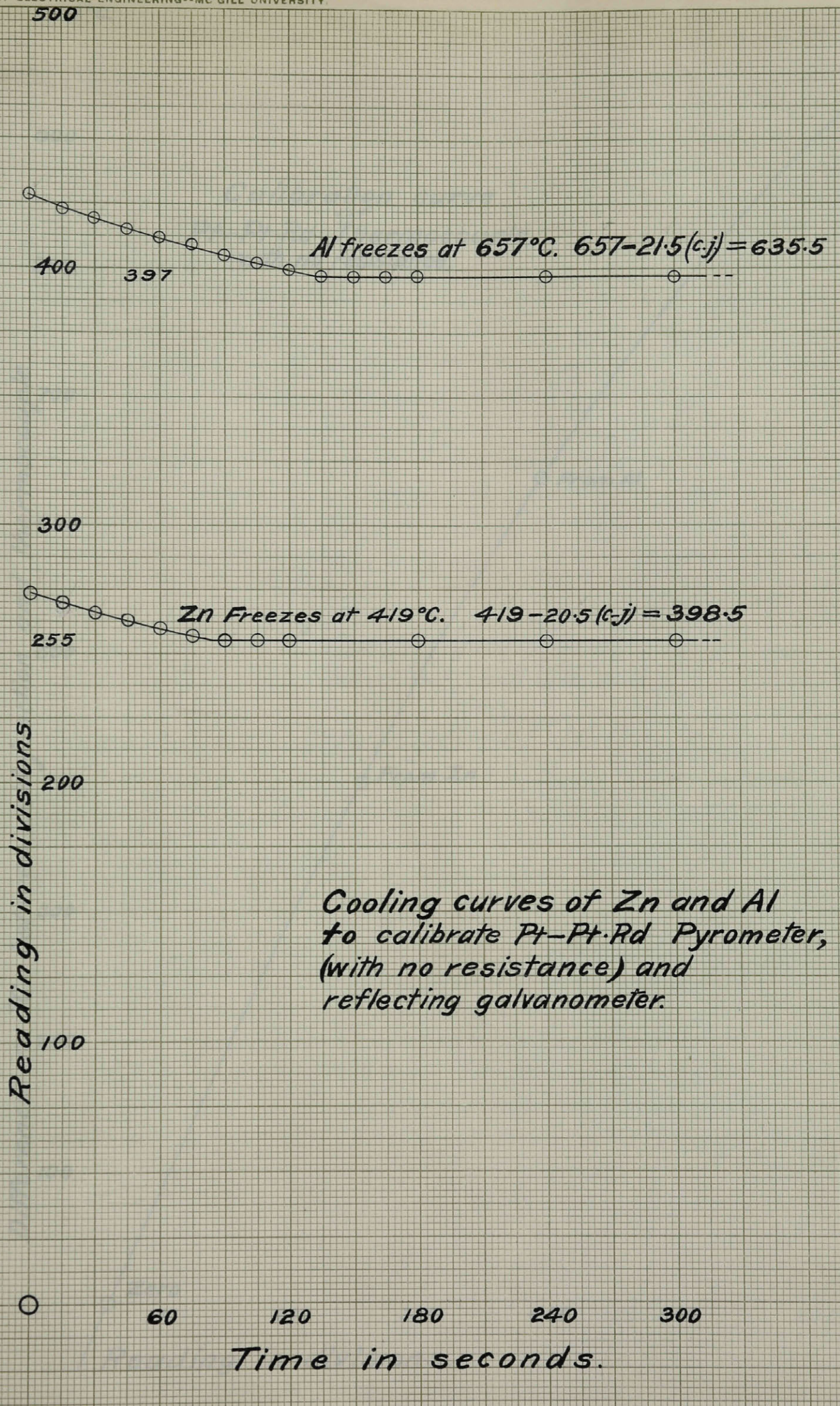
In order to check this calculation, and to some extent calibrate the drop test machine, five bars of steel 160, having an average cross section of 1.61" X .48", were tested by steady loads, with the usual span of 11", with the following results:

Average load = 4060 lbs. Average skin stress = 180,000 #/□"

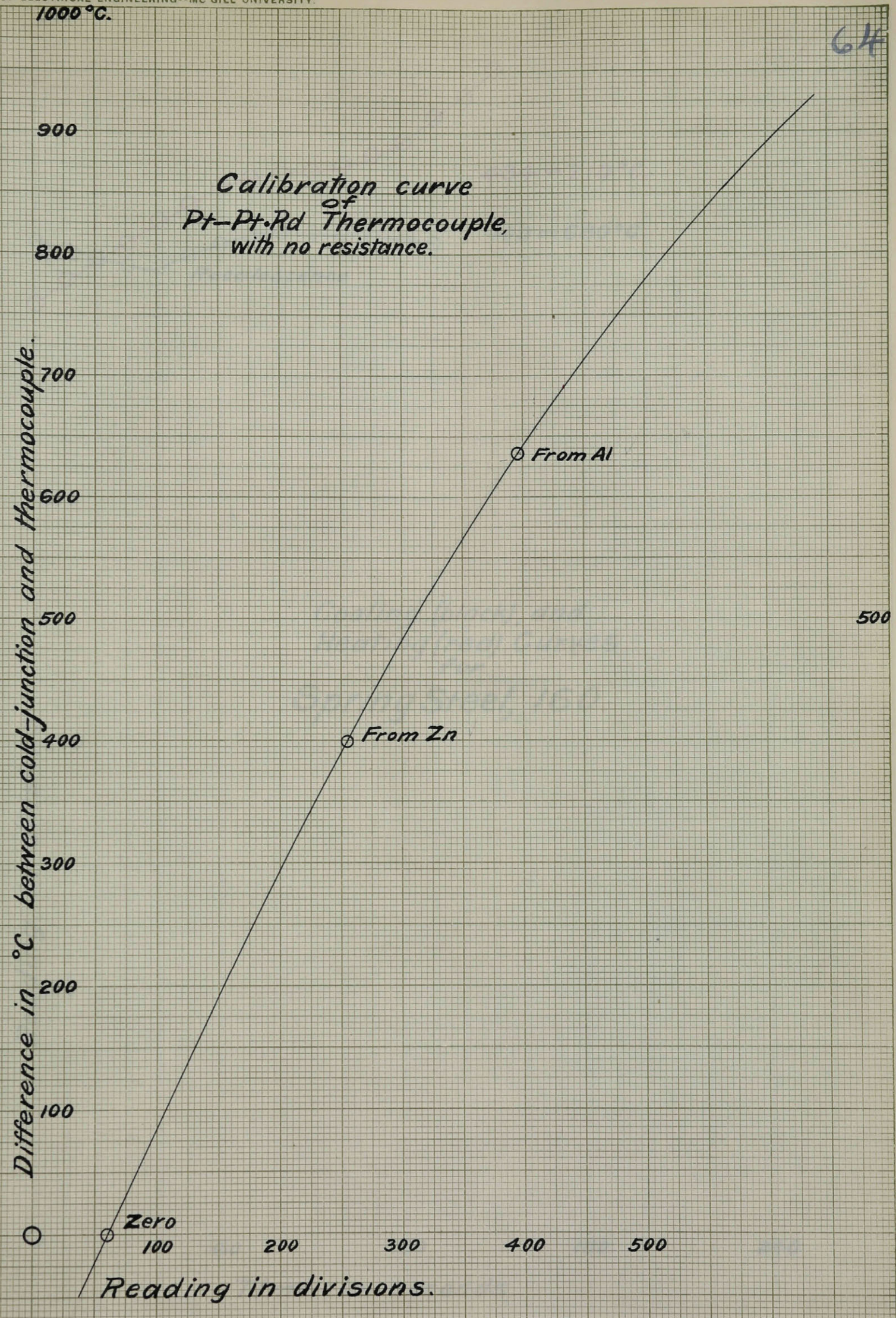
Average total movement = 0.24". Average permanent set = 0.002".

The same bars were then further tested, as follows:

Four broke before attaining a total movement of 0.50", the average breaking load being 6260 lbs. The fifth carried 6600 and received a permanent set of 0.072". One bar, deflected to 0.375", received a set of 0.014". The maximum breaking load was 7450 lbs., giving a skin stress of 330,000 lbs. per sq.in.; this bar deflected 0.47".



Cooling curves of Zn and Al to calibrate Pt–Pt·Rd Pyrometer, (with no resistance) and reflecting galvanometer.


1000 °C.
900
800
700
600
500
400
300
200
100
0
Difference in °C between cold-junction and thermocouple.
Calibration curve
of
Pt–Pt.Rd Thermocouple,
with no resistance.
From Al
From Zn
Zero
100
200
300
400
500
500
Reading in divisions.

300

Cooling (black), and
Heating (red) Curves
for
Spring Steel, 160.

200

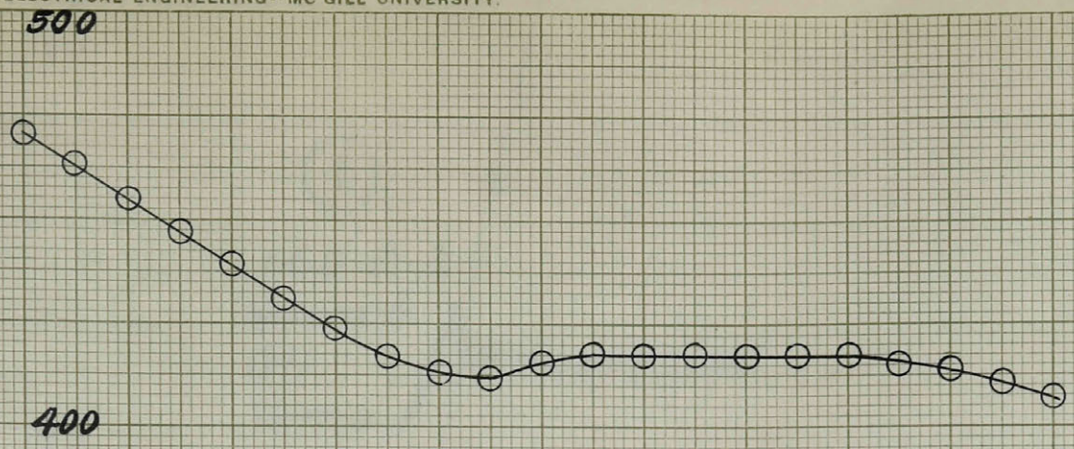
Reading in divisions

100

0

60 120 180 240

Time in seconds.



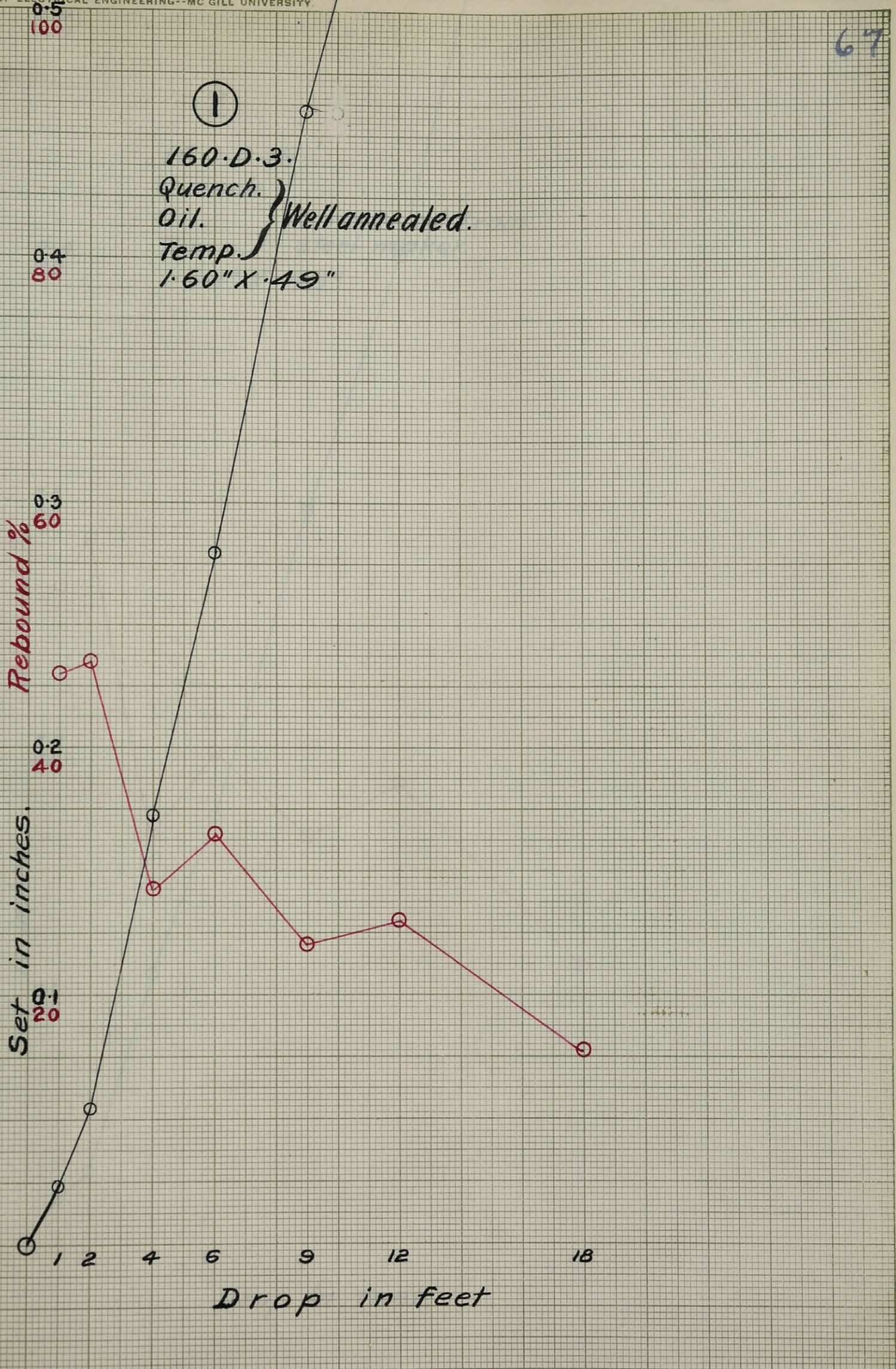
Cooling Curve
for
Spring Steel, 161.

Reading in divisions.

300
200
100
0

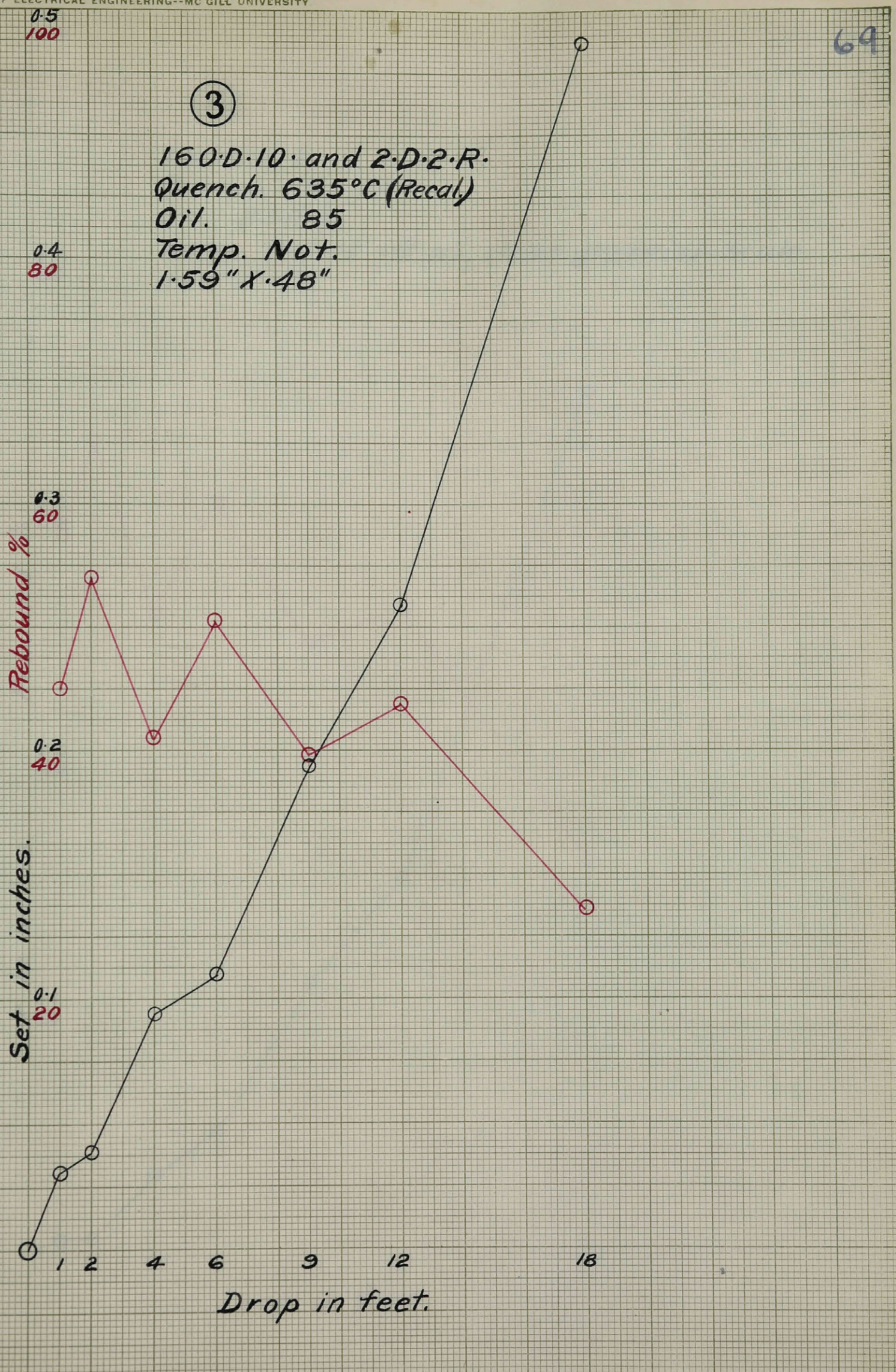
60 120 180

Time in seconds.



(2)

160·D·16·
Quench.) Oil.
Temp.} As received from steel maker.
1·64" X·48"

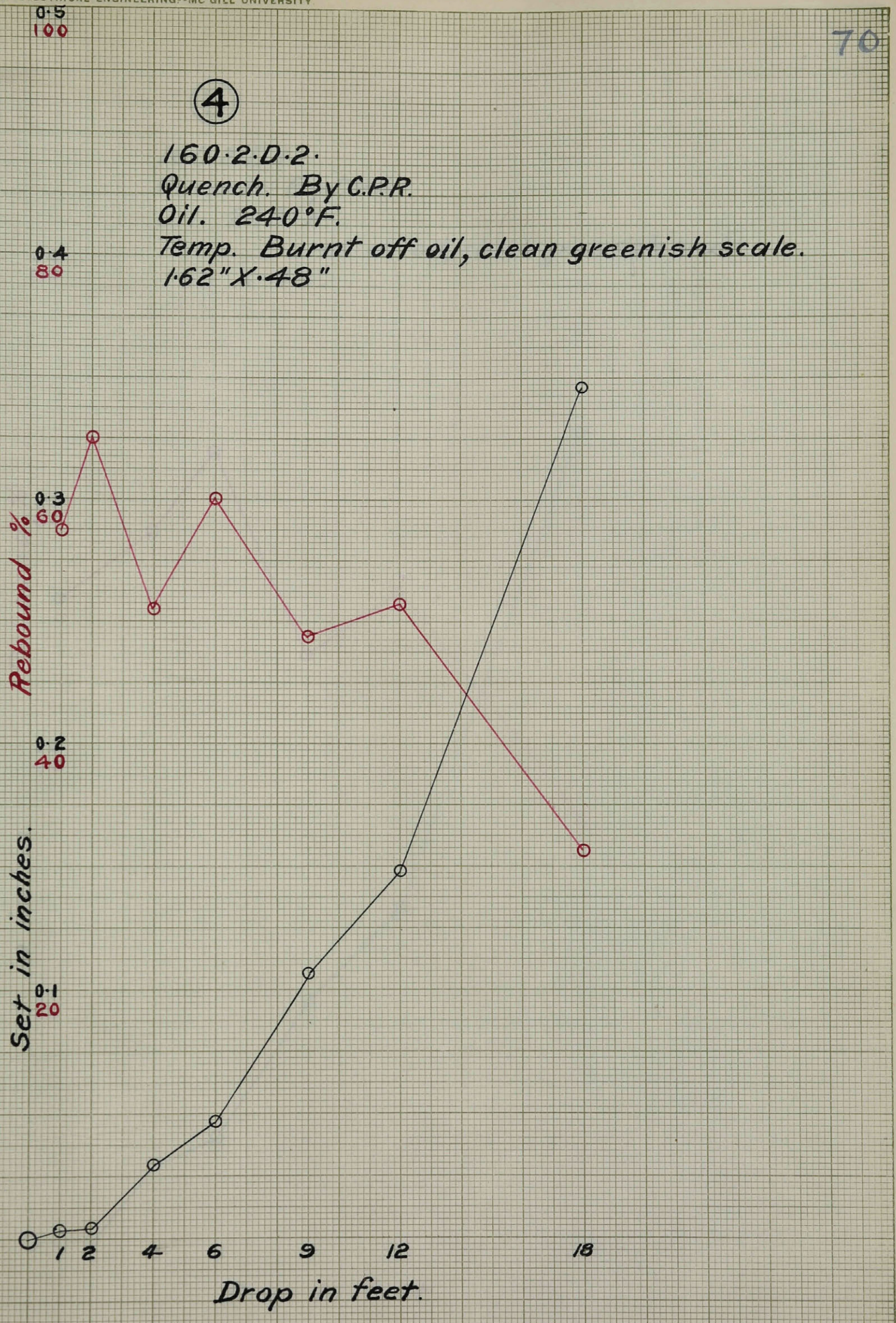


③

160·D·10· and 2·D·2·R·
Quench. 635°C (Recal.)
Oil. 85
Temp. Not.
1·59" X·48"

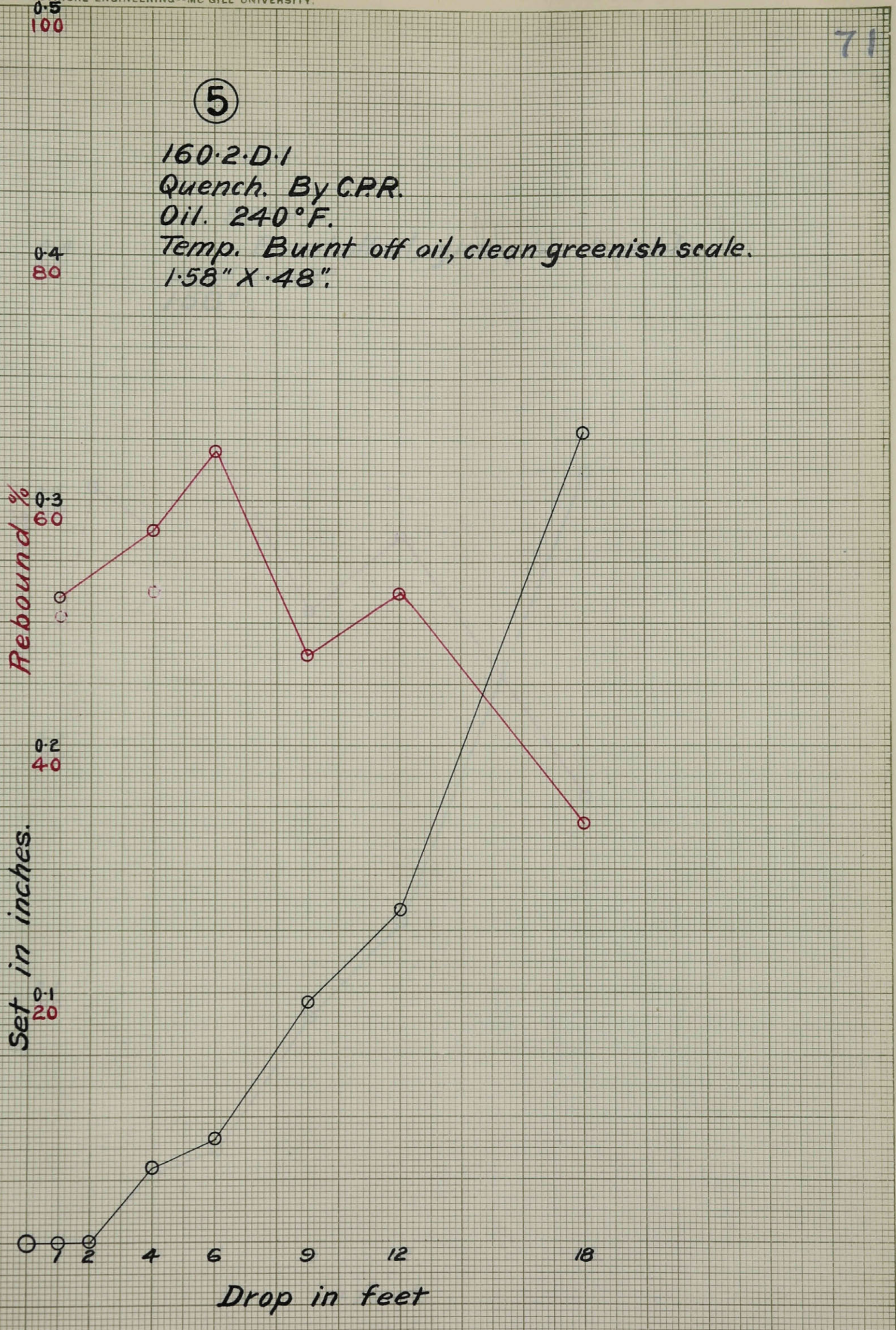
④

160·2·D·2·
Quench. By C.P.R.
Oil. 240°F.
Temp. Burnt off oil, clean greenish scale.
1·62"X·48"



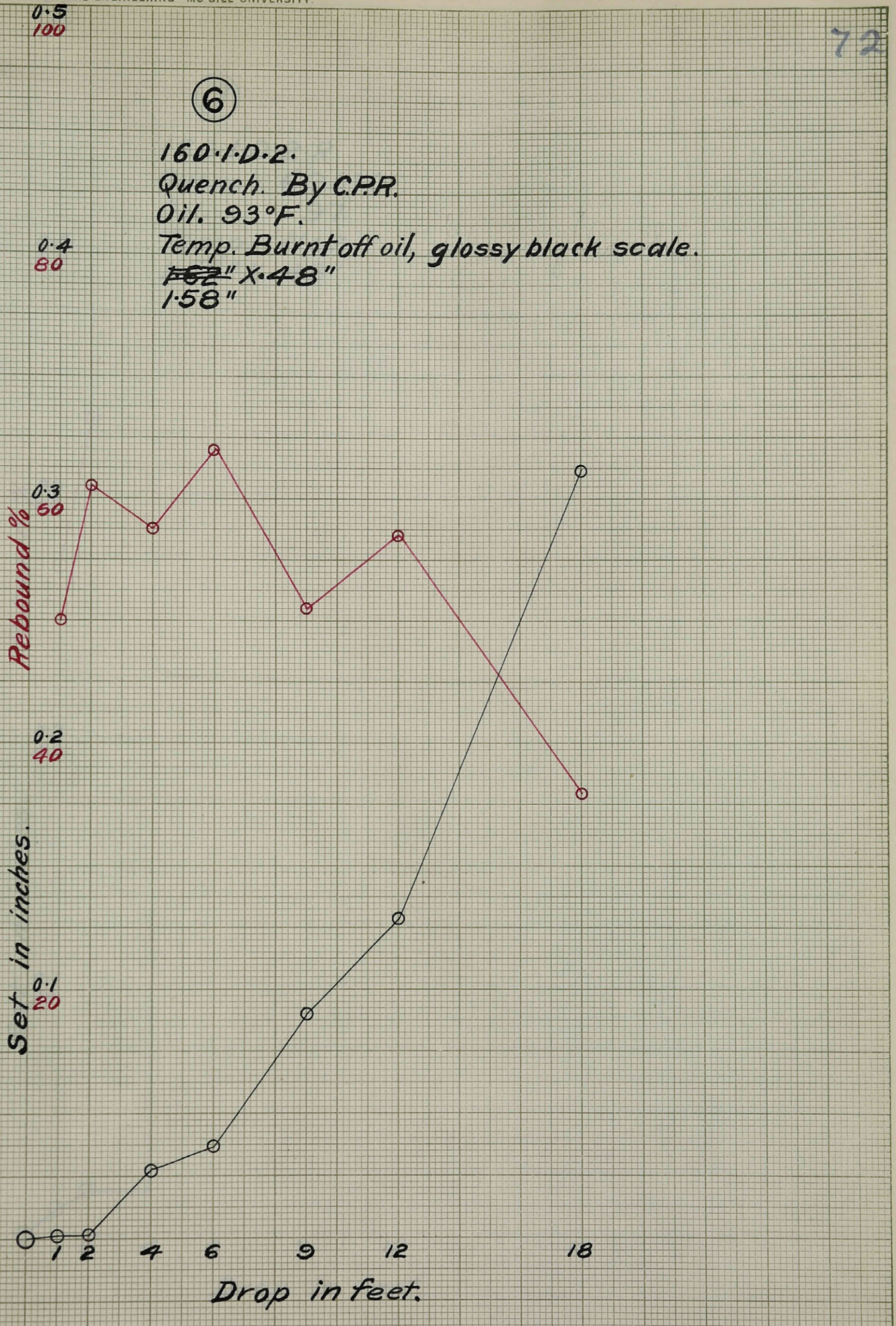
(5)

160·2·D·1
Quench. By C.P.R.
Oil. 240° F.
Temp. Burnt off oil, clean greenish scale.
1·58" X ·48".



(6)

160·1·D·2·
Quench. By C.P.R.
Oil. 93°F.
Temp. Burnt off oil, glossy black scale.
~~1·62~~" X·48"
1·58"

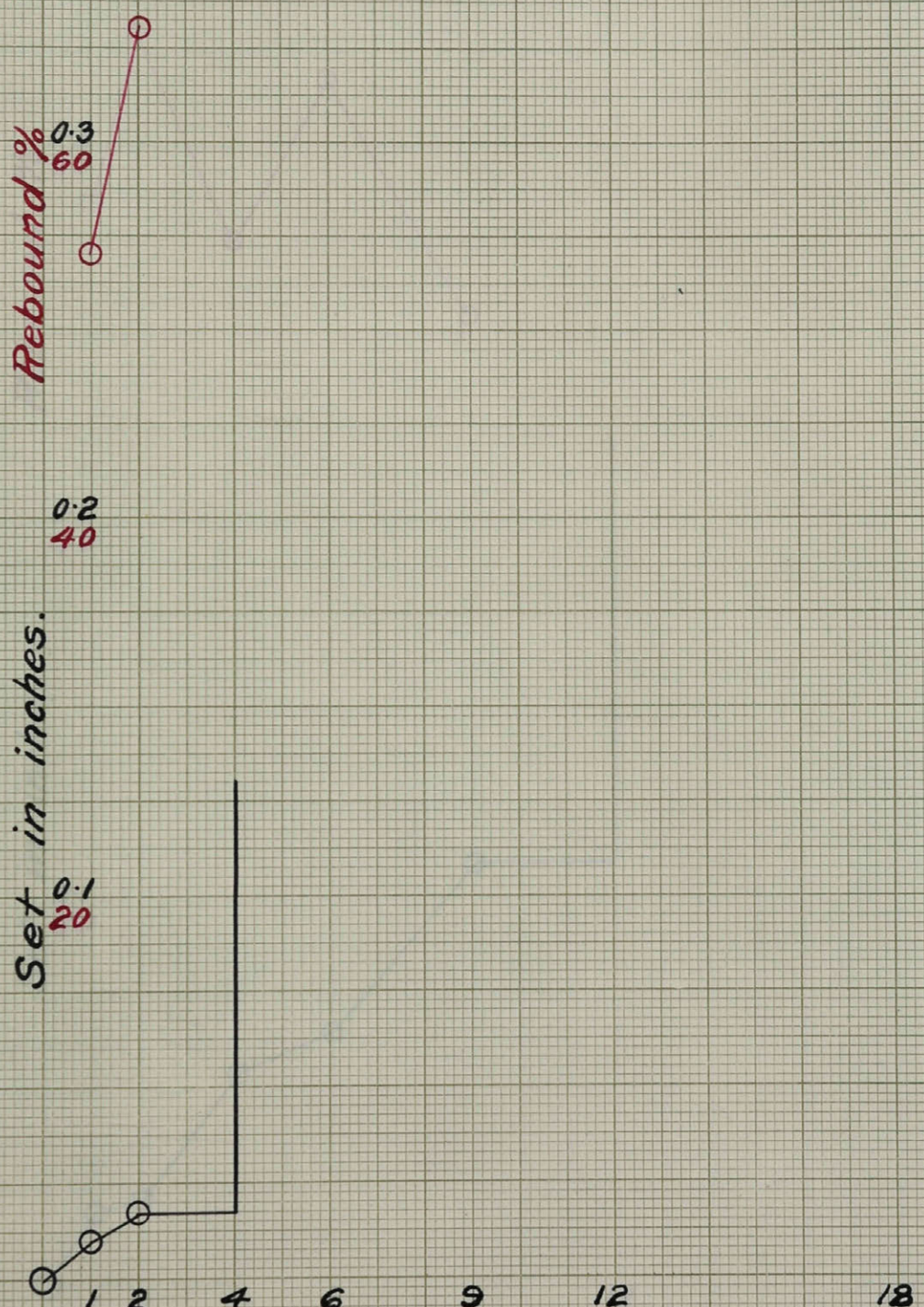


0·5
100

⑦

160·1·D·2·R
Quench. 690°C
Oil. 97
Temp. Not
1·58" X·48"

0·4
80

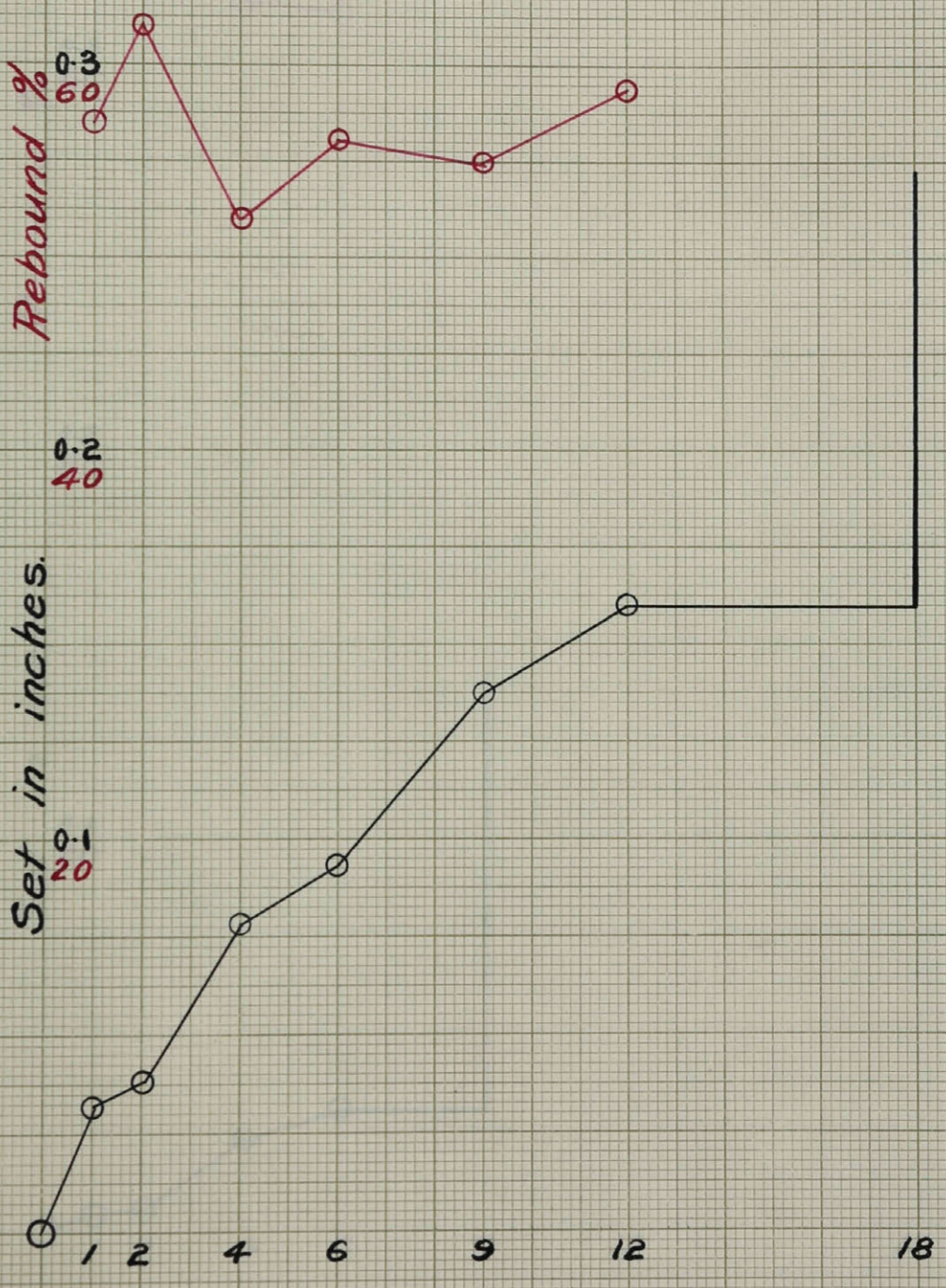


(8)

160·D·11·
Quench. 655 °C.
Oil. 90
Temp. Not.
1·63" X·49"

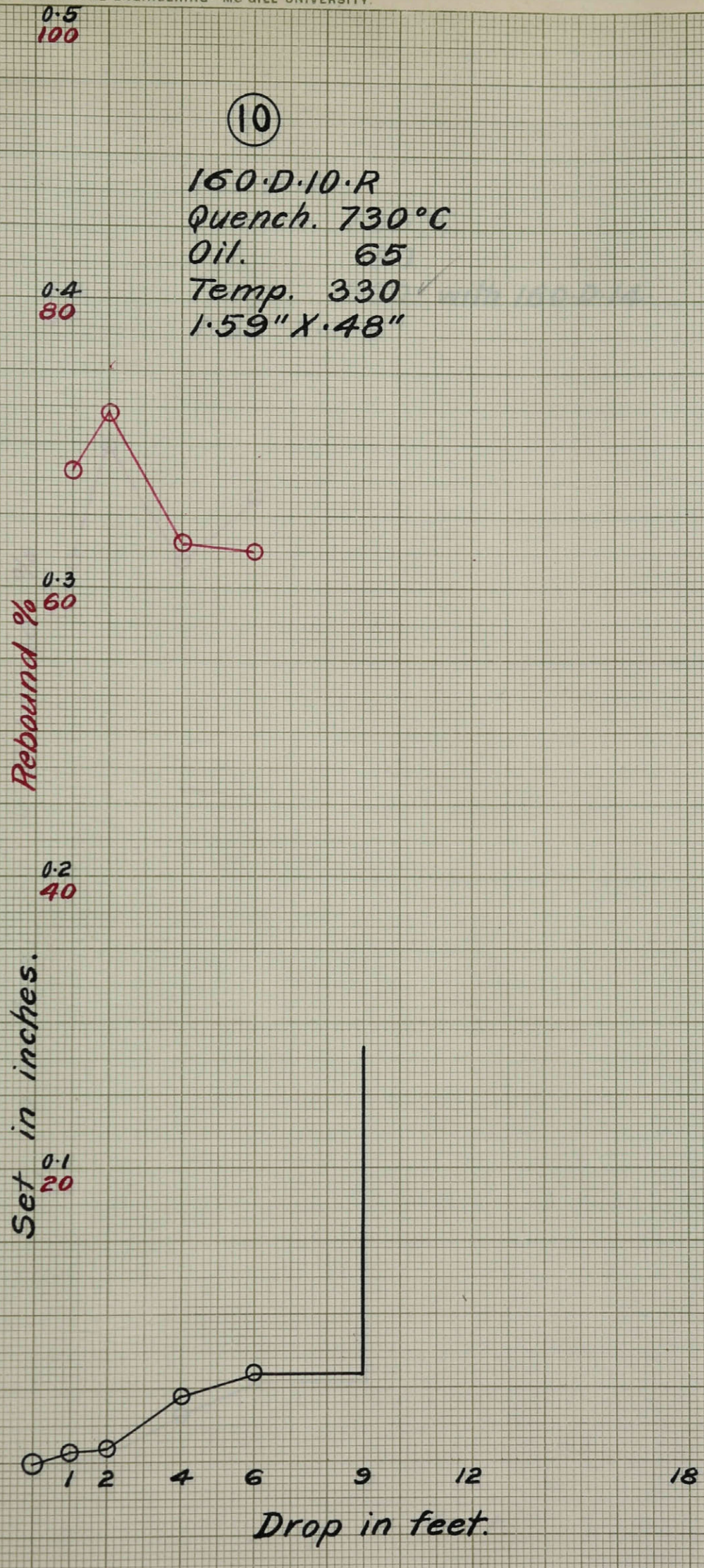
(9)

160·2·D·1·R
Quench. 655°C.
Oil. 96
Temp. Not
1·58" X·48"



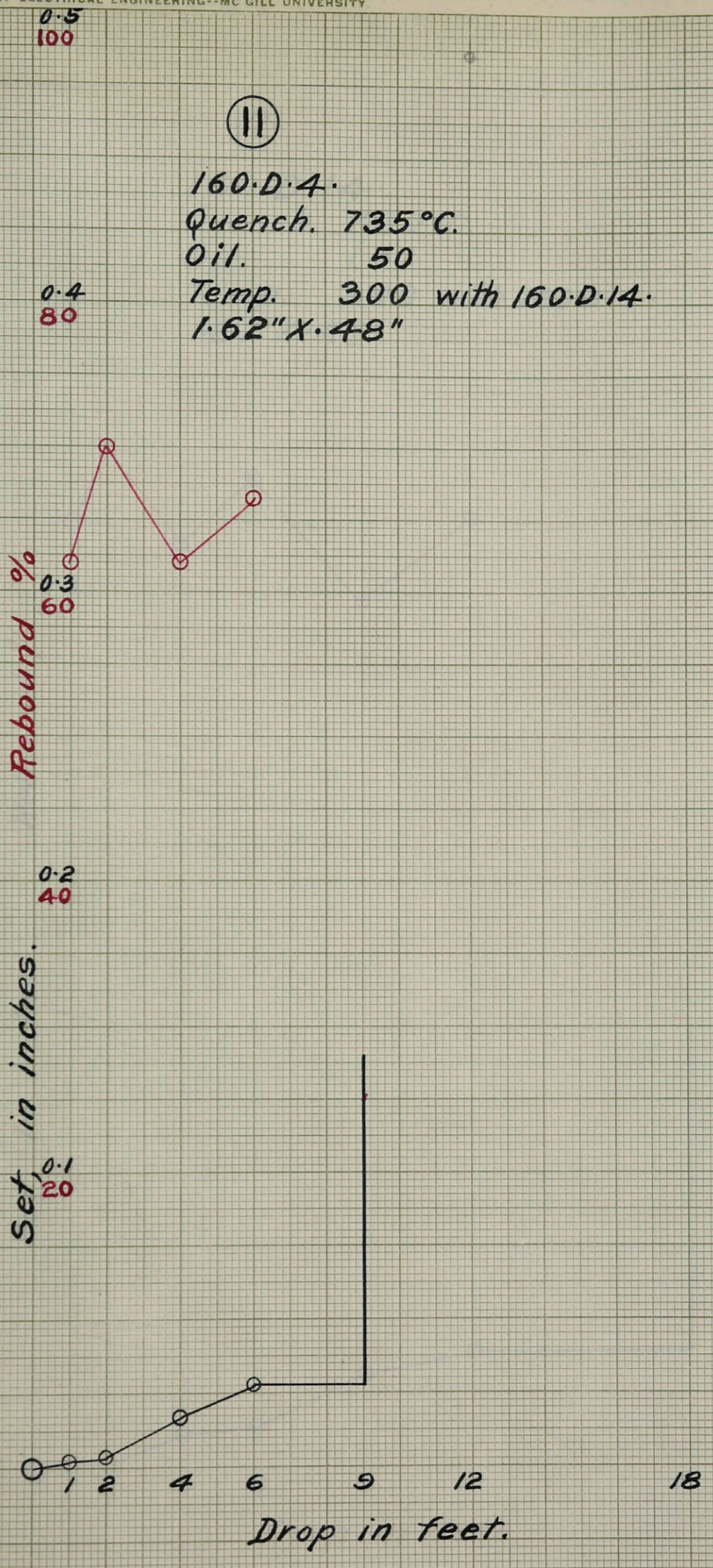
(10)

160·D·10·R
Quench. 730°C
Oil. 65
Temp. 330
1·59" X·48"



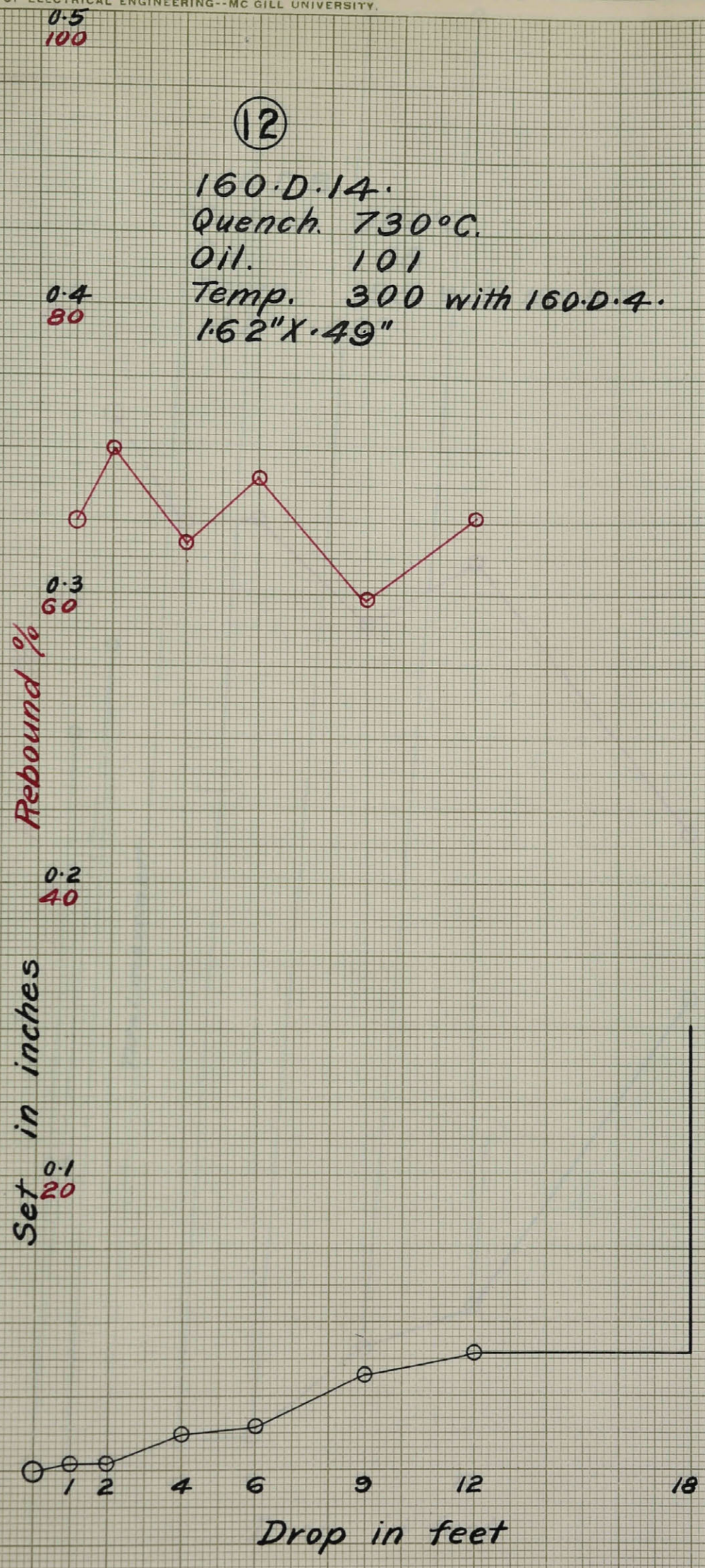
(11)

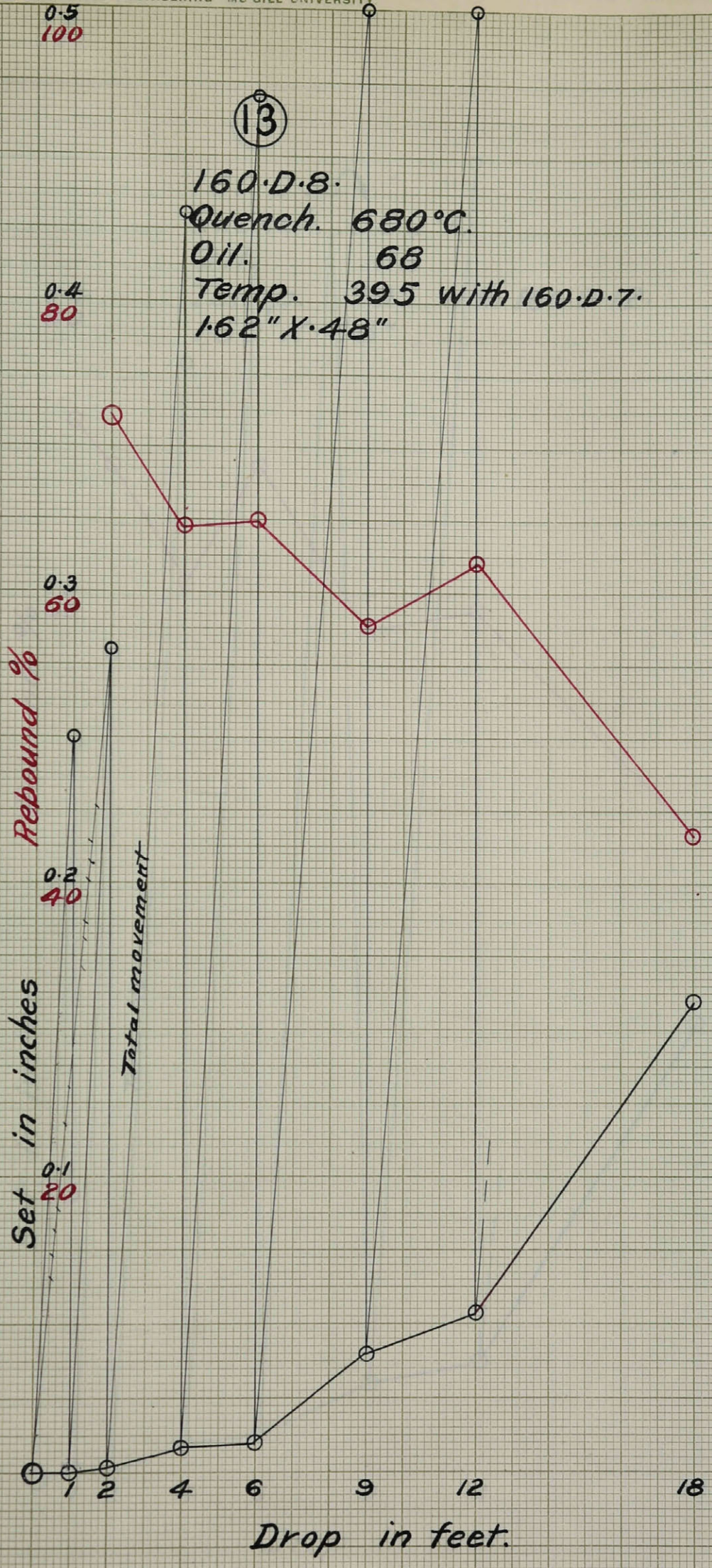
160·D·4.
Quench. 735°C.
Oil. 50
Temp. 300 with 160·D·14.
1·62"X·48"

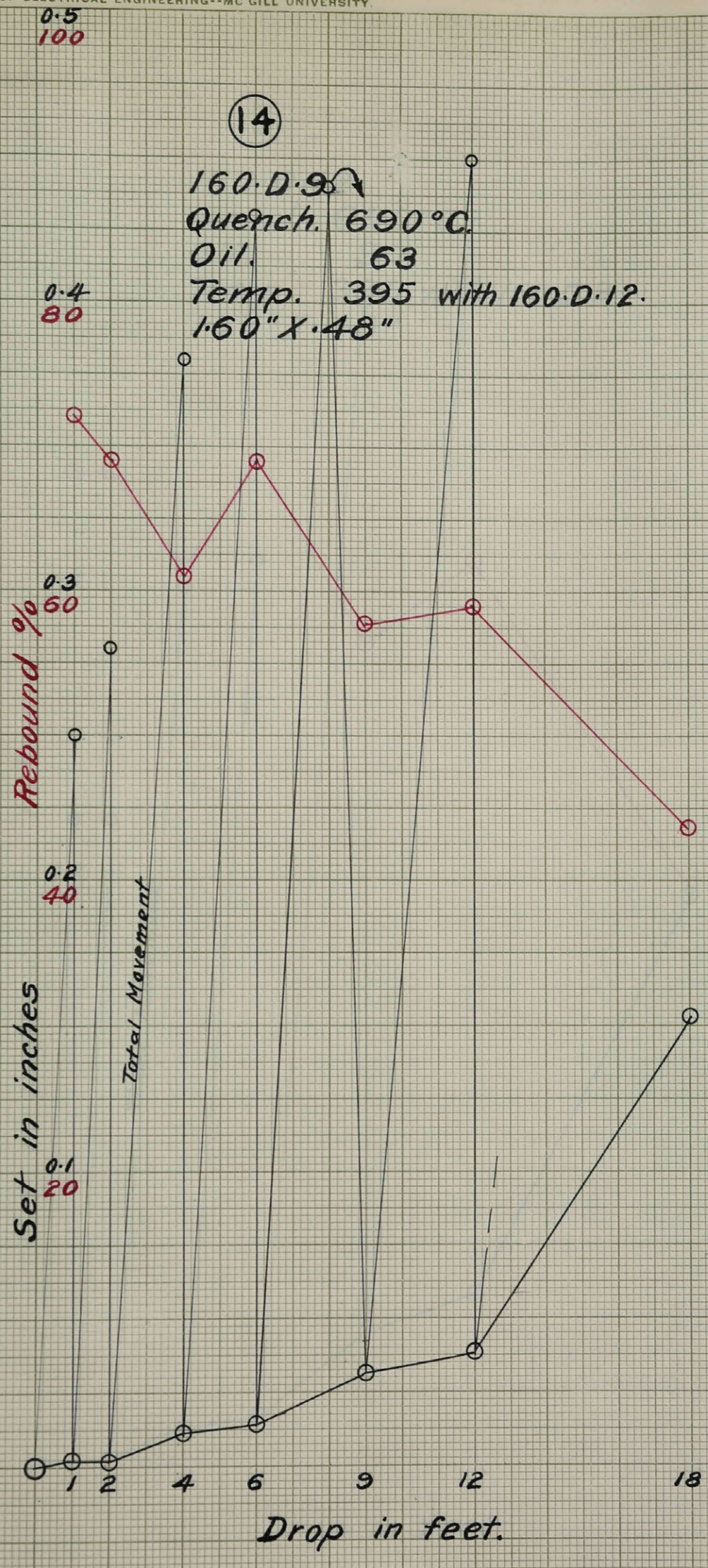


(12)

160·D·14.
Quench. 730°C.
Oil. 101
Temp. 300 with 160·D·4.
1·62"X·49"

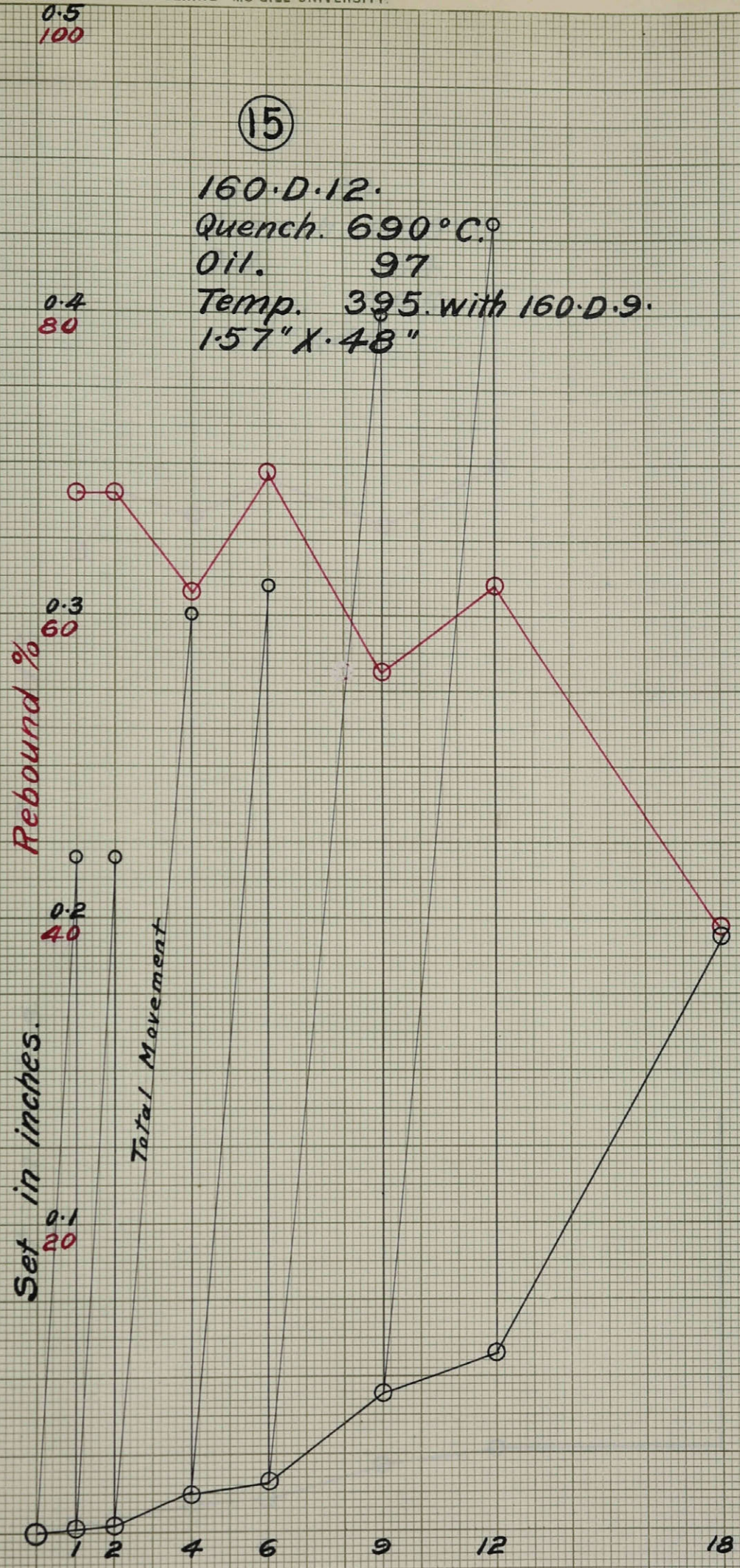



13
160·D·8·
Quench. 680°C.
Oil. 68
Temp. 395 with 160·D·7·
1·62" X·48"
0·5
100
0·4
80
0·3
60
0·2
40
0·1
20
Rebound %
Set in inches
Total movement
1
2
4
6
9
12
18
Drop in feet.


14
160·D·9
Quench. 690°C.
Oil. 63
Temp. 395 with 160·D·12.
1·60" X ·48"
0·5
100
0·4
80
0·3
60
0·2
40
0·1
20
Rebound %
Set in inches
Total Movement
1
2
4
6
9
12
18
Drop in feet.

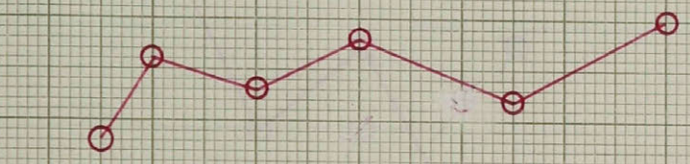
(15)

160·D·12·
Quench. 690°C.
Oil. 97
Temp. 395. with 160·D·9·
1·57" X·48"



(16)

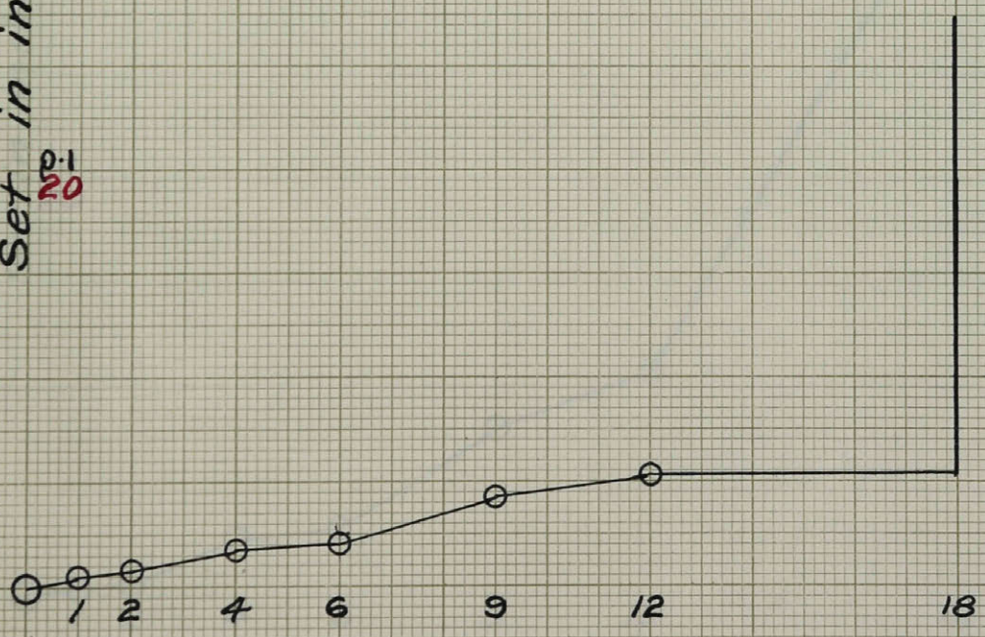
160·D·20
Quench. 695°C.
Oil. 64
Temp. 395
1:55"X·48"



0·5 100
0·4 80
0·3 60
0·2 40
0·1 20

Rebound %

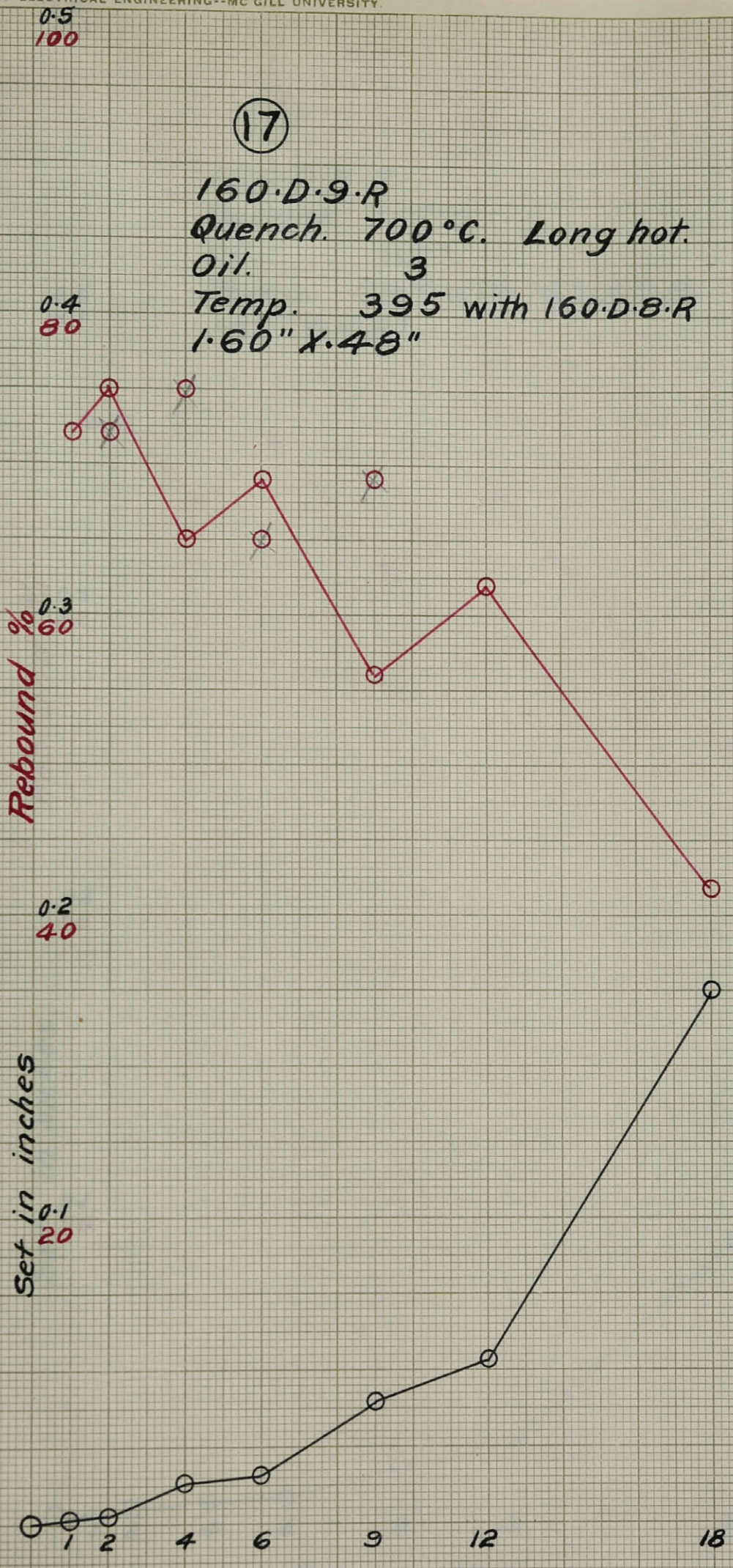
Set in inches.



Drop in feet.

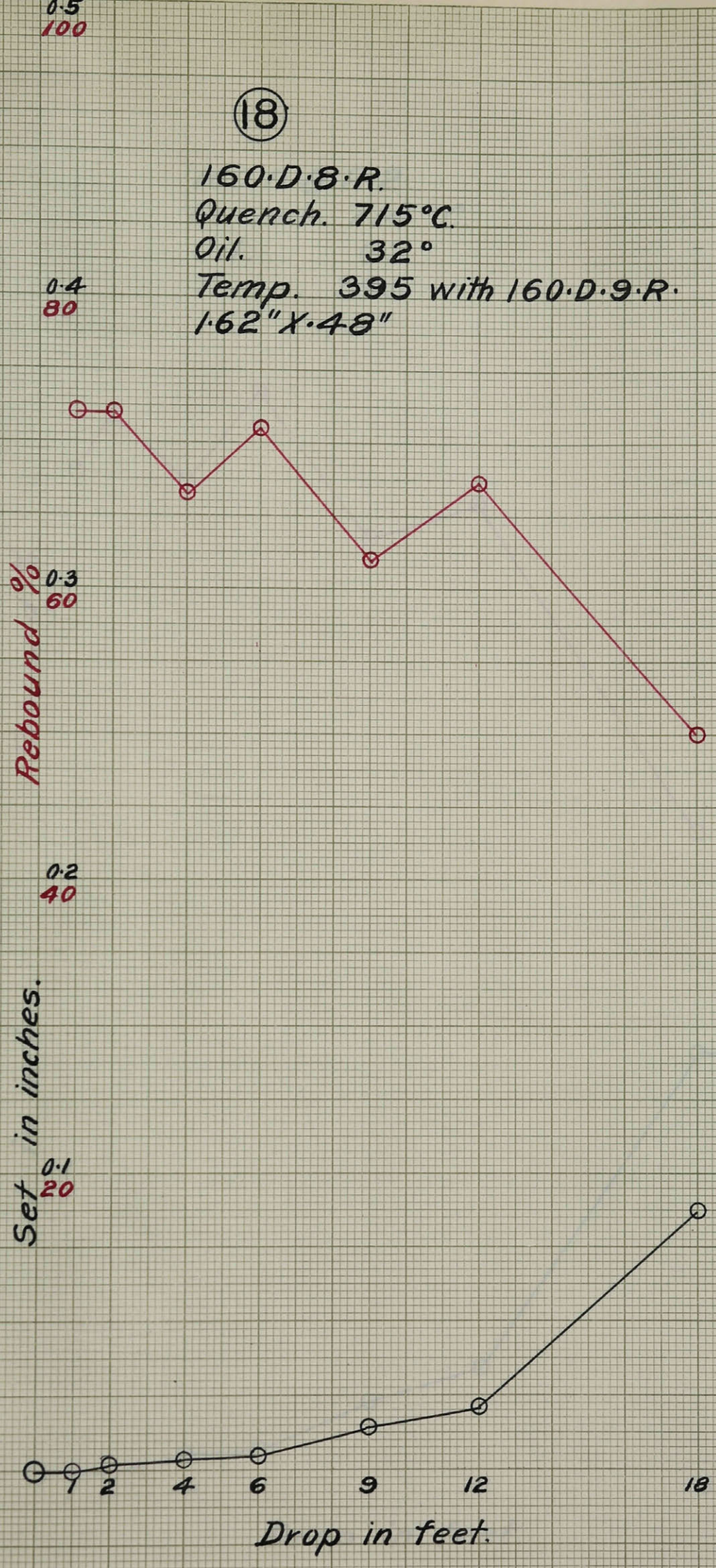
(17)

160·D·9·R
Quench. 700°C. Long hot.
Oil. 3
Temp. 395 with 160·D·8·R
1·60" X·48"



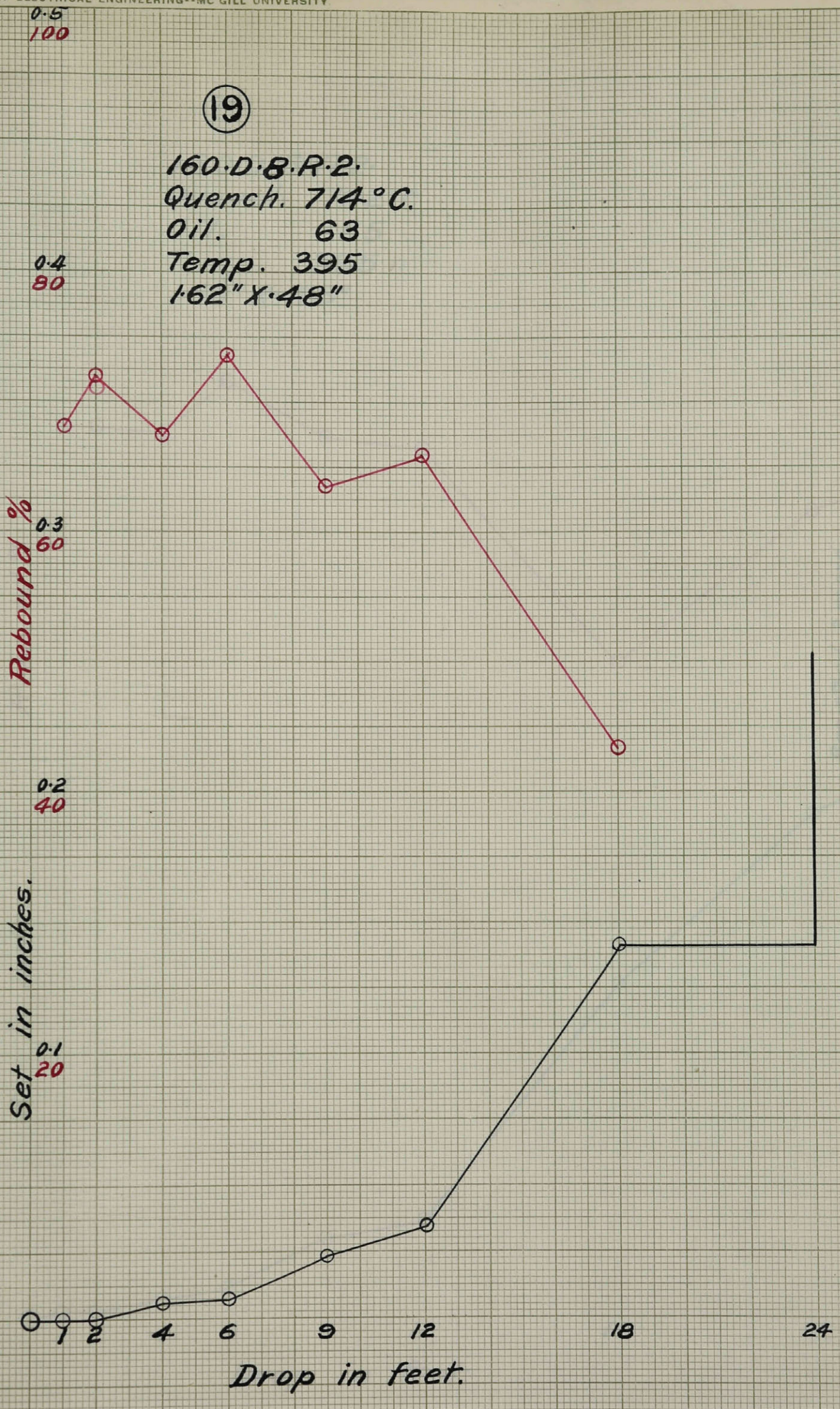
(18)

160·D·8·R.
Quench. 715°C.
Oil. 32°
Temp. 395 with 160·D·9·R.
1·62"X·48"



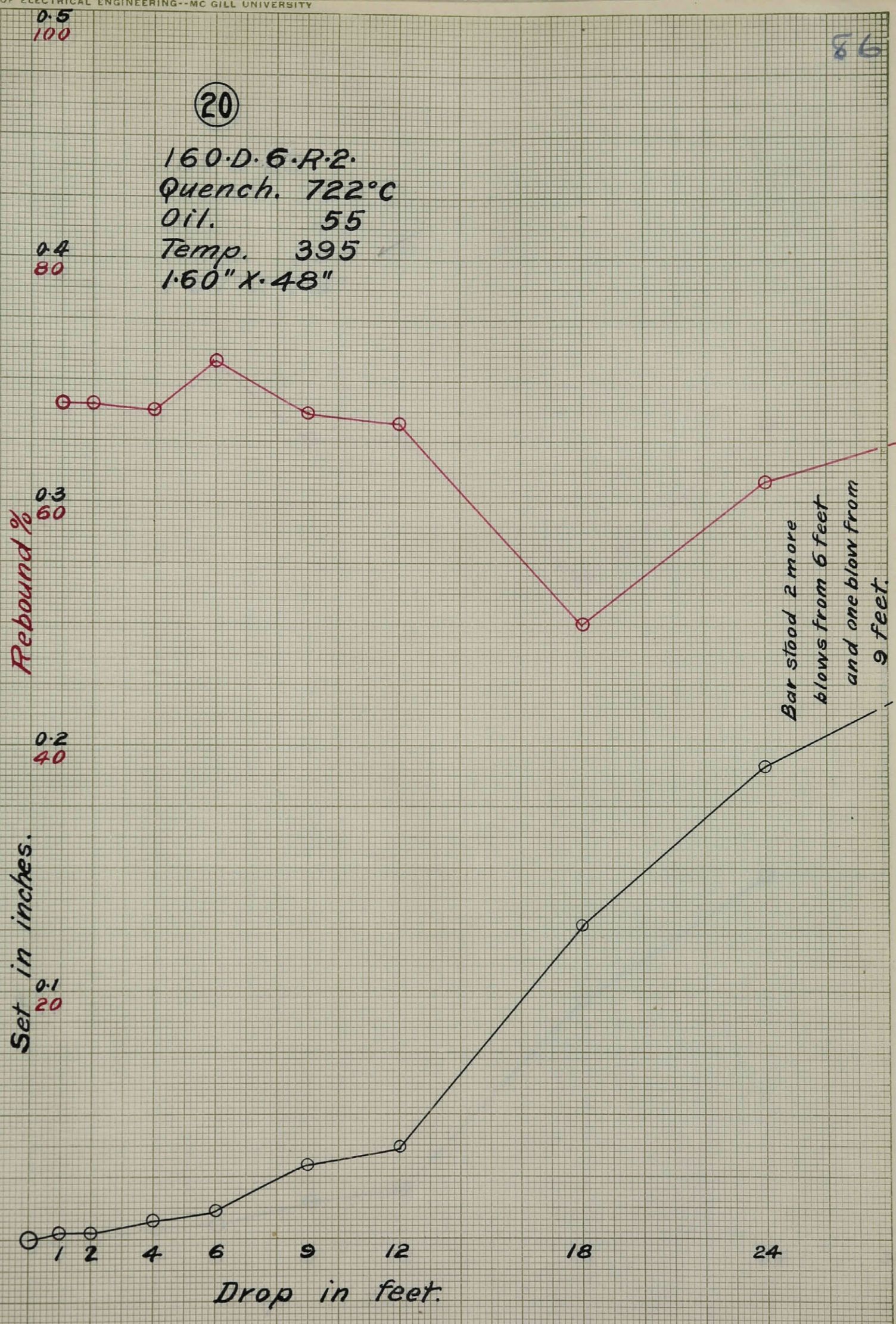
(19)

160·D·8·R·2·
Quench. 714°C.
Oil. 63
Temp. 395
1·62" X·48"



(20)

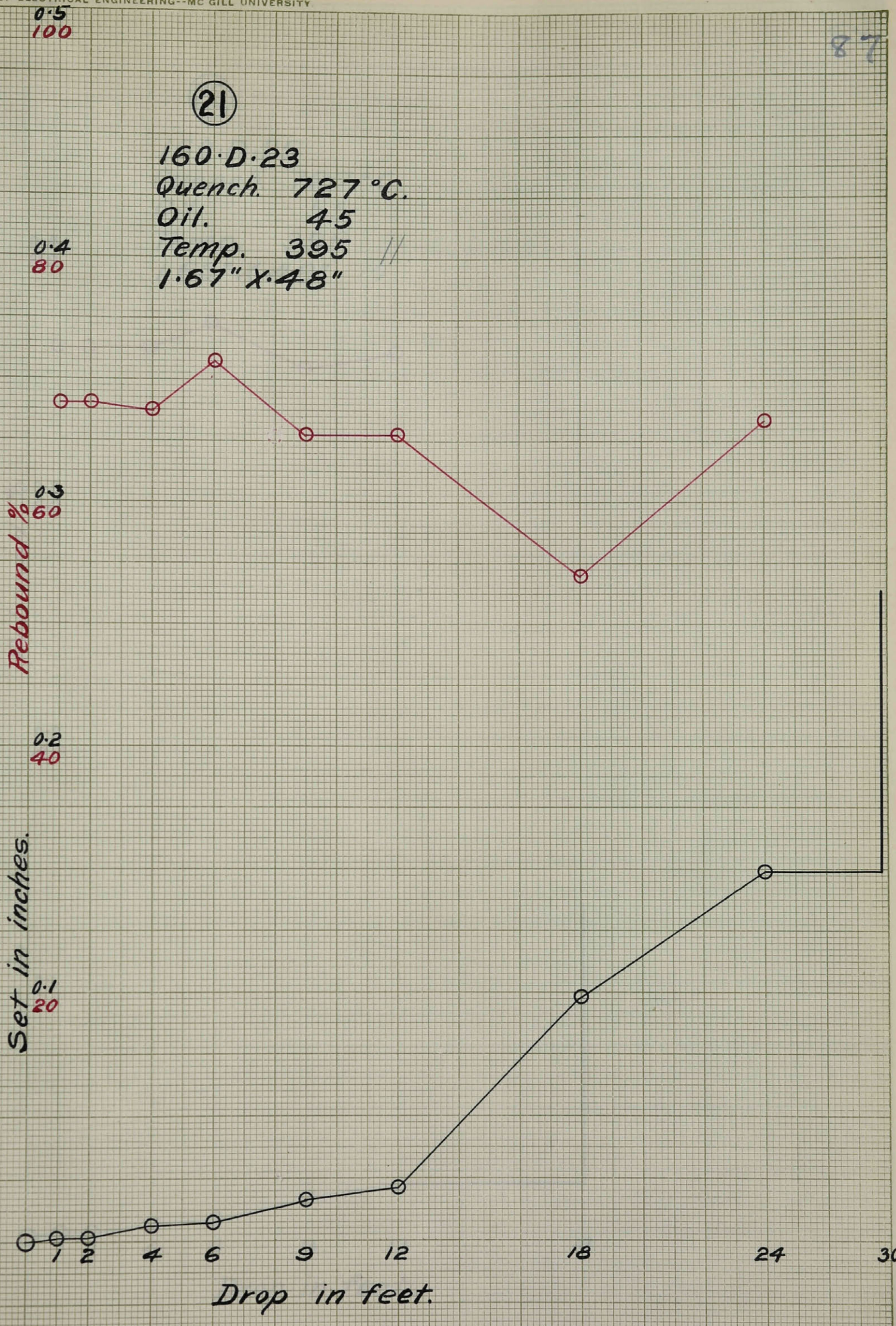
160·D·6·R·2·
Quench. 722°C
Oil. 55
Temp. 395
1·60" X·48"



87

(21)

160·D·23
Quench. 727 °C.
Oil. 45
Temp. 395 //
1·67" X·48"

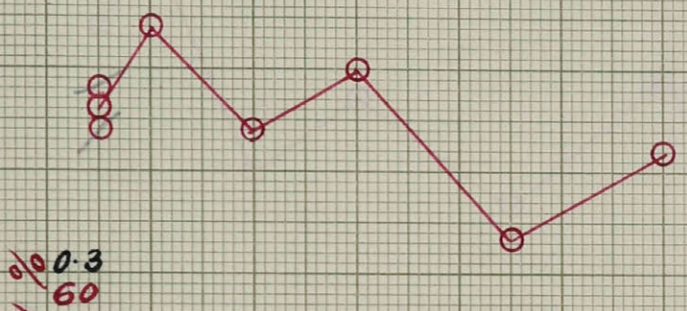


(22)

160·D·25
Quench. 727°C.
Oil. 55
Temp. 395
1.63" X .48"

23

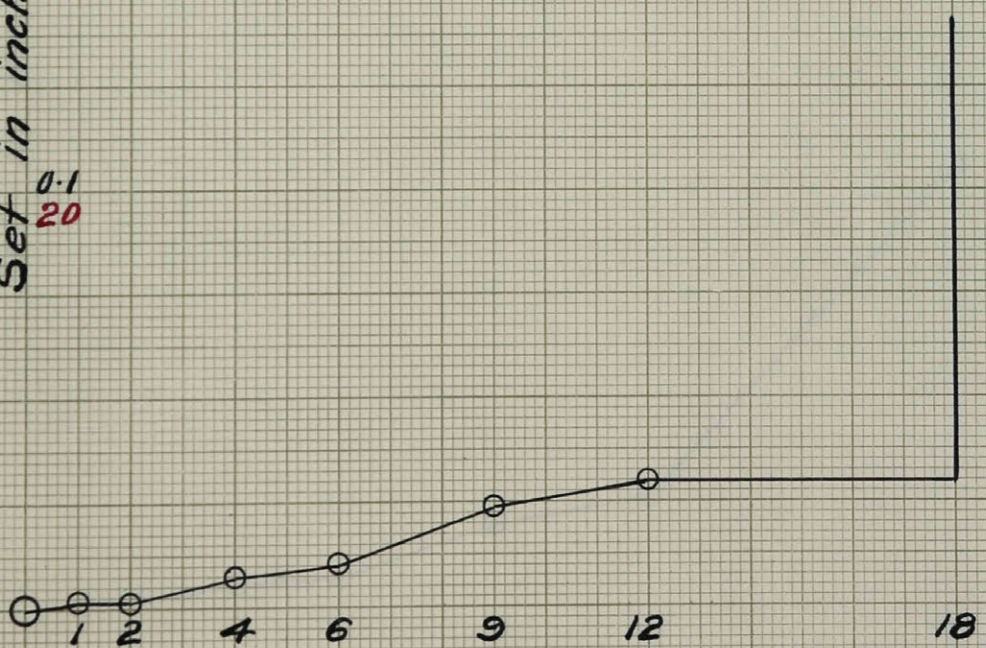
160·D·12·R
Quench. 730°C
Oil. 20
Temp. 395 with 160·D·13·R·
1·57" X·48"



0·5 100
0·4 80
0·3 60
0·2 40
0·1 20

Rebound %

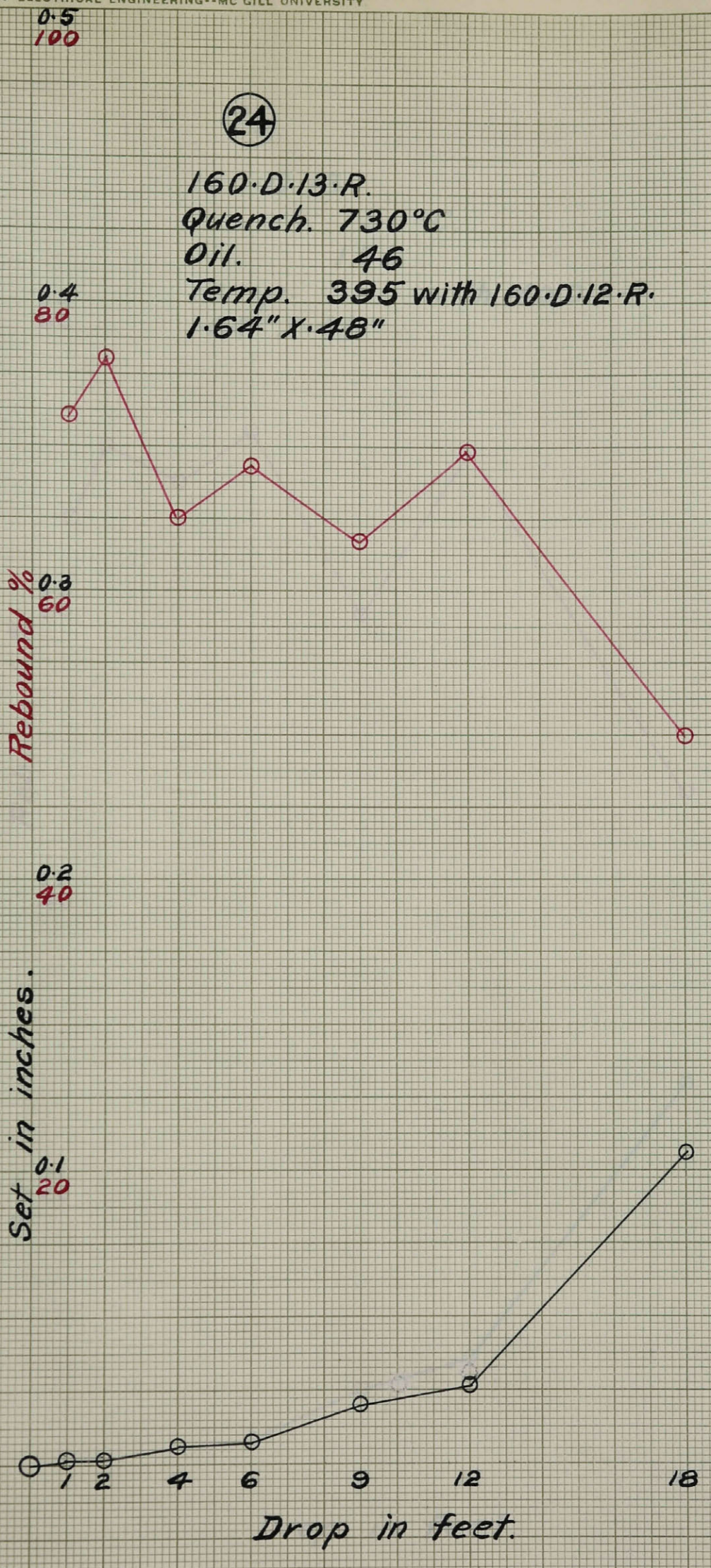
Set in inches.



Drop in feet.

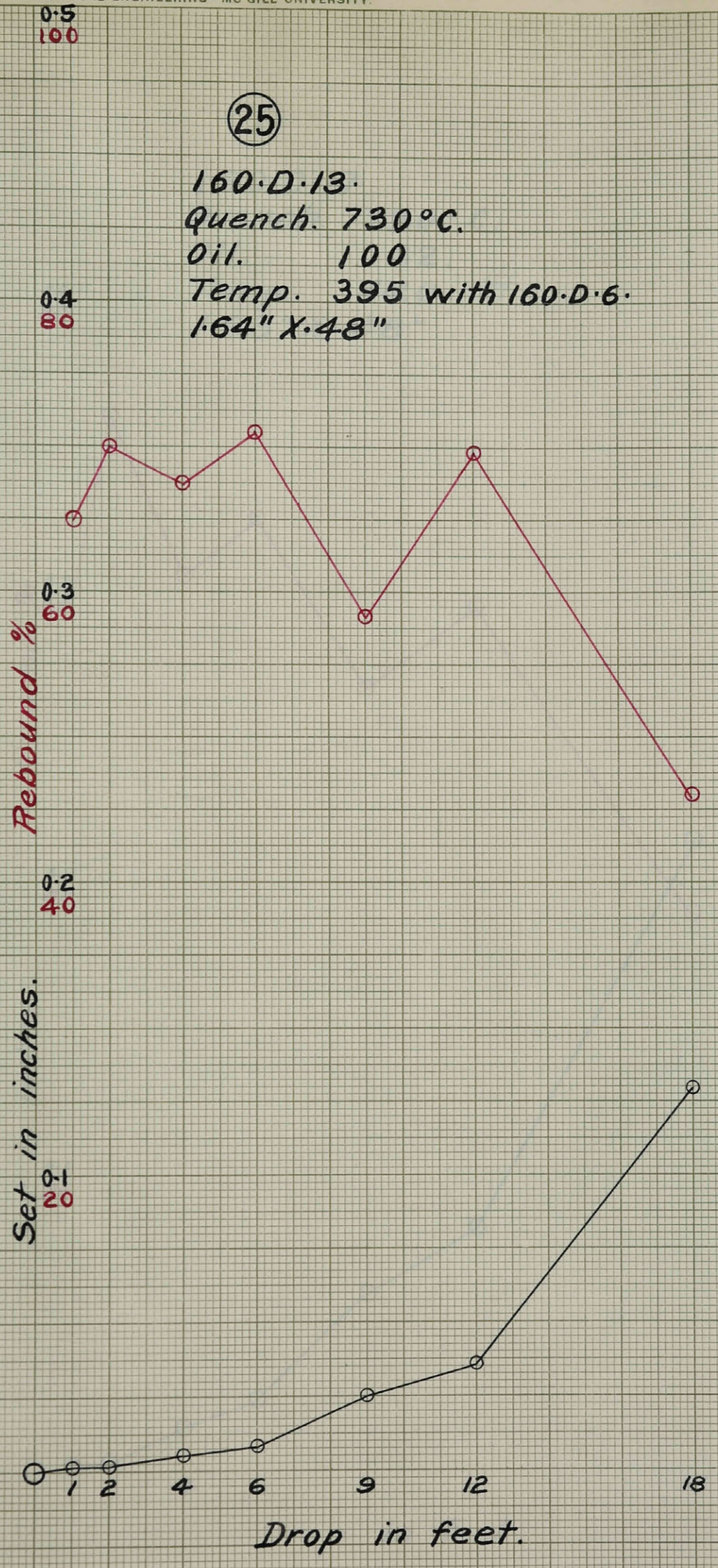
(24)

160·D·13·R.
Quench. 730°C
Oil. 46
Temp. 395 with 160·D·12·R.
1·64" X·48"



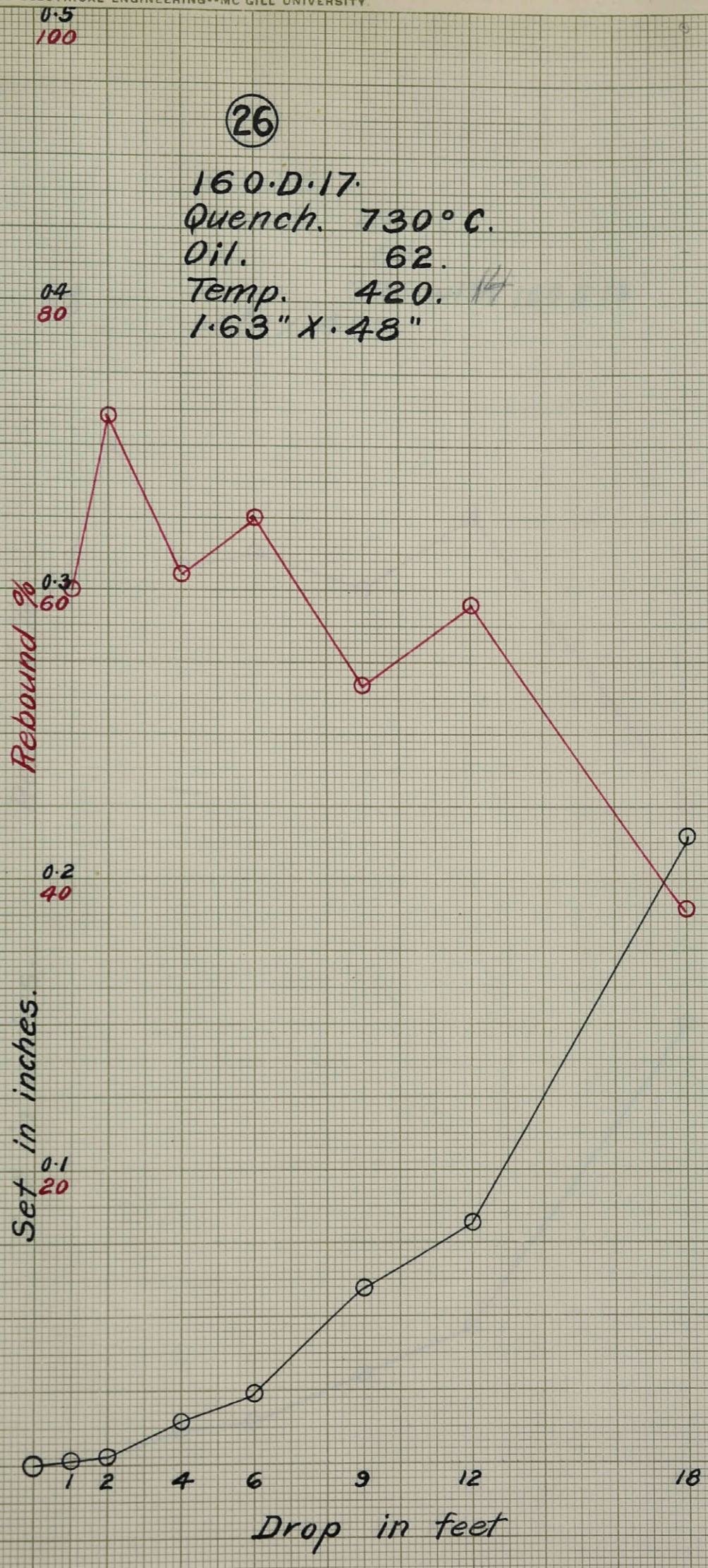
(25)

160·D·13·
Quench. 730°C.
Oil. 100
Temp. 395 with 160·D·6·
1·64" X·48"



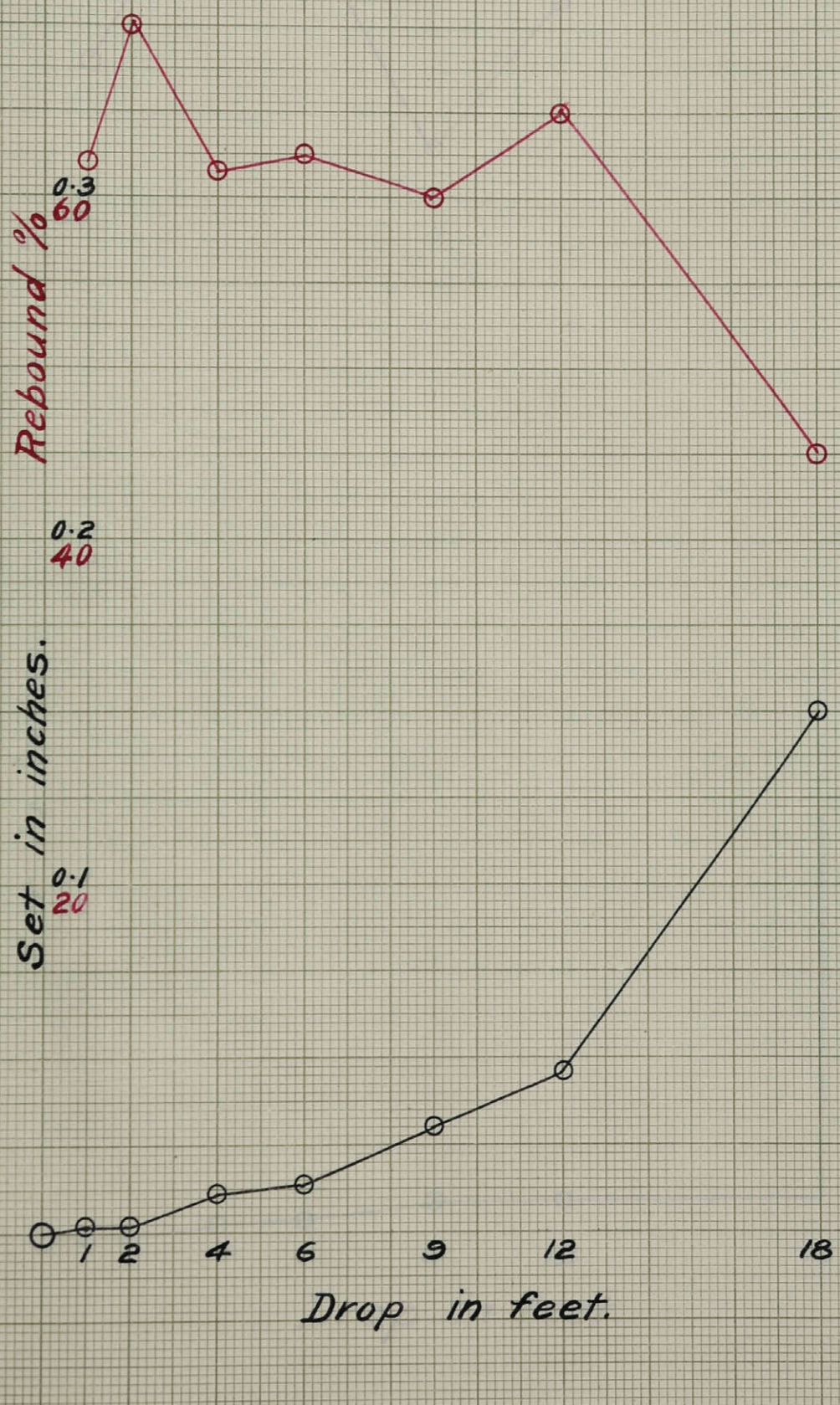
(26)

160·D·17·
Quench. 730° C.
Oil. 62.
Temp. 420.
1·63" X ·48"



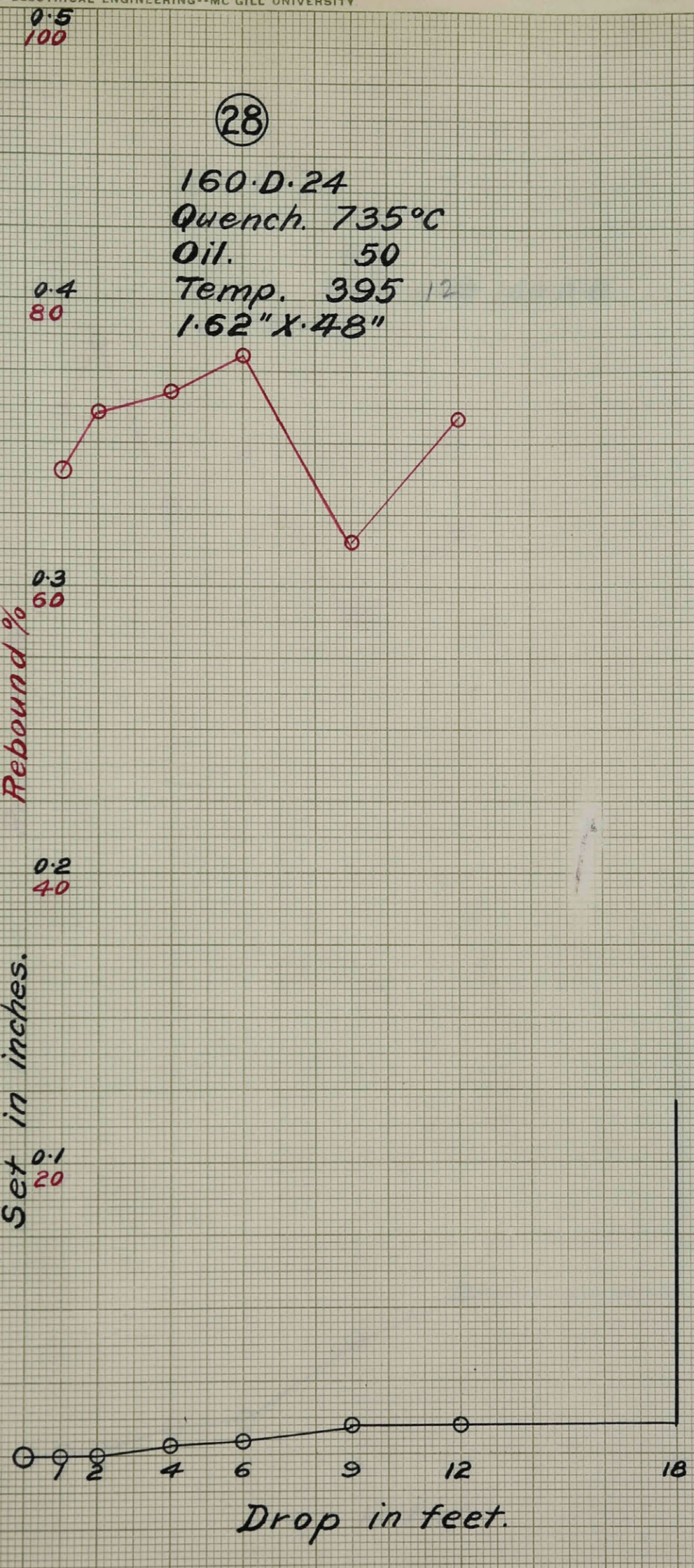
(27)

160·D·6·
Quench. 735°C.
Oil. 60
Temp. 395 with 160·D·13
1·60" X·48"



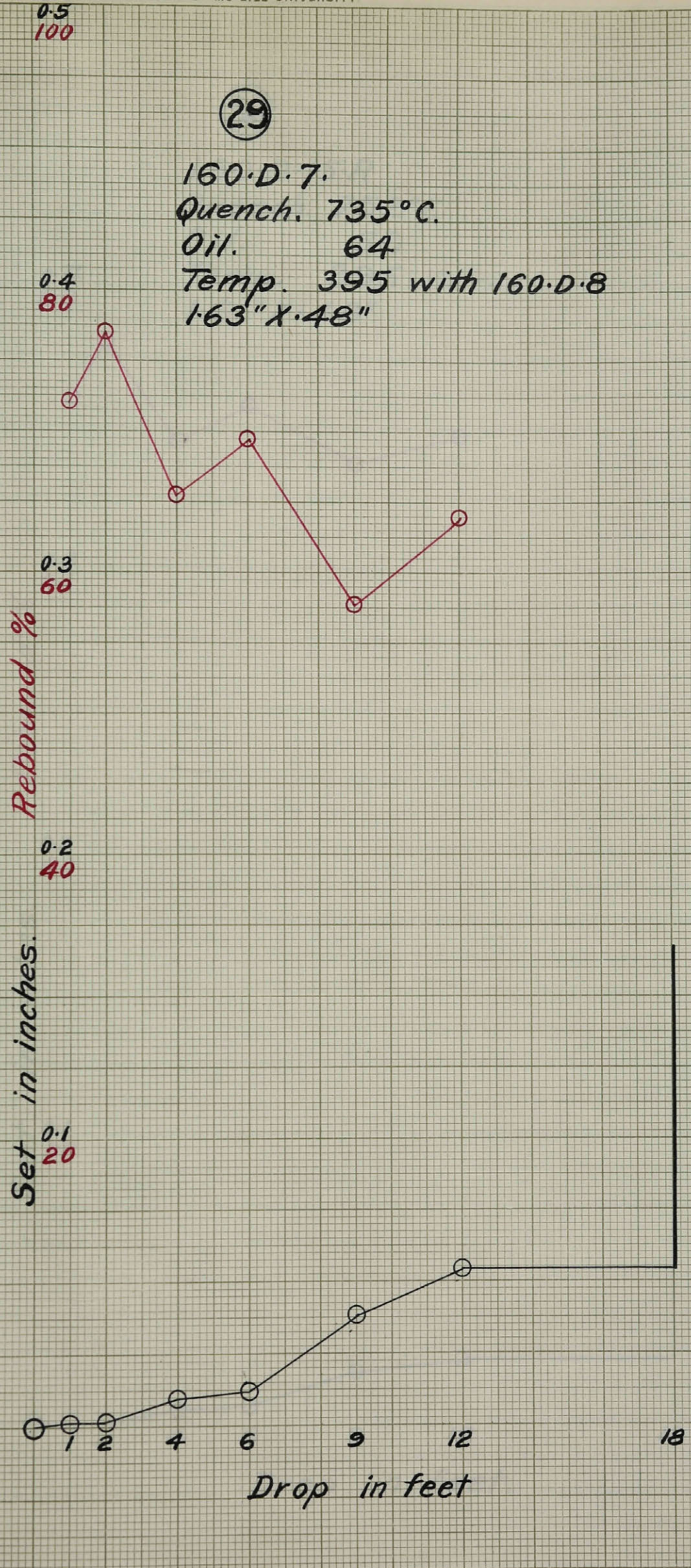
(28)

160·D·24
Quench. 735°C
Oil. 50
Temp. 395
1.62" X .48"



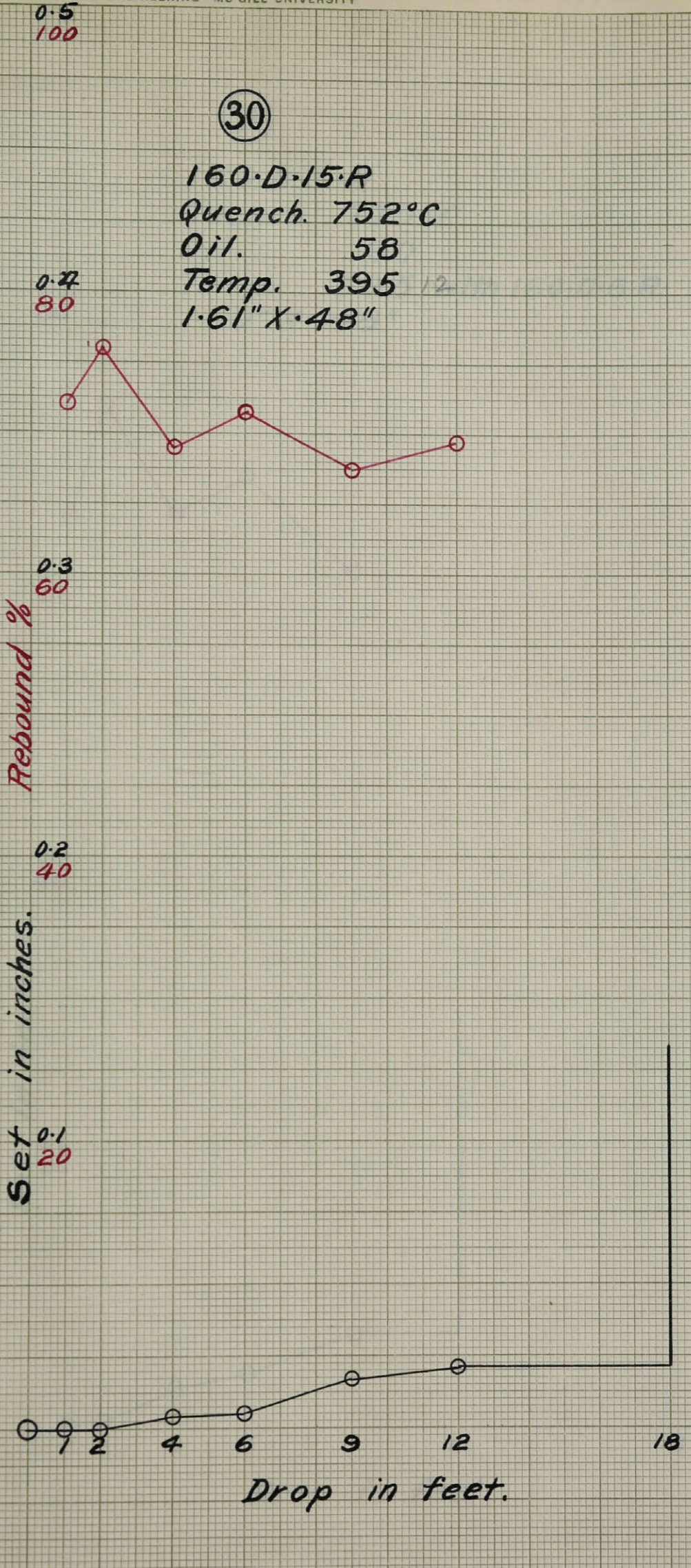
(29)

160·D·7·
Quench. 735°C.
Oil. 64
Temp. 395 with 160·D·8
1·63" X·48"



(30)

160·D·15·R
Quench. 752°C
Oil. 58
Temp. 395
1·61" X ·48"



(31)

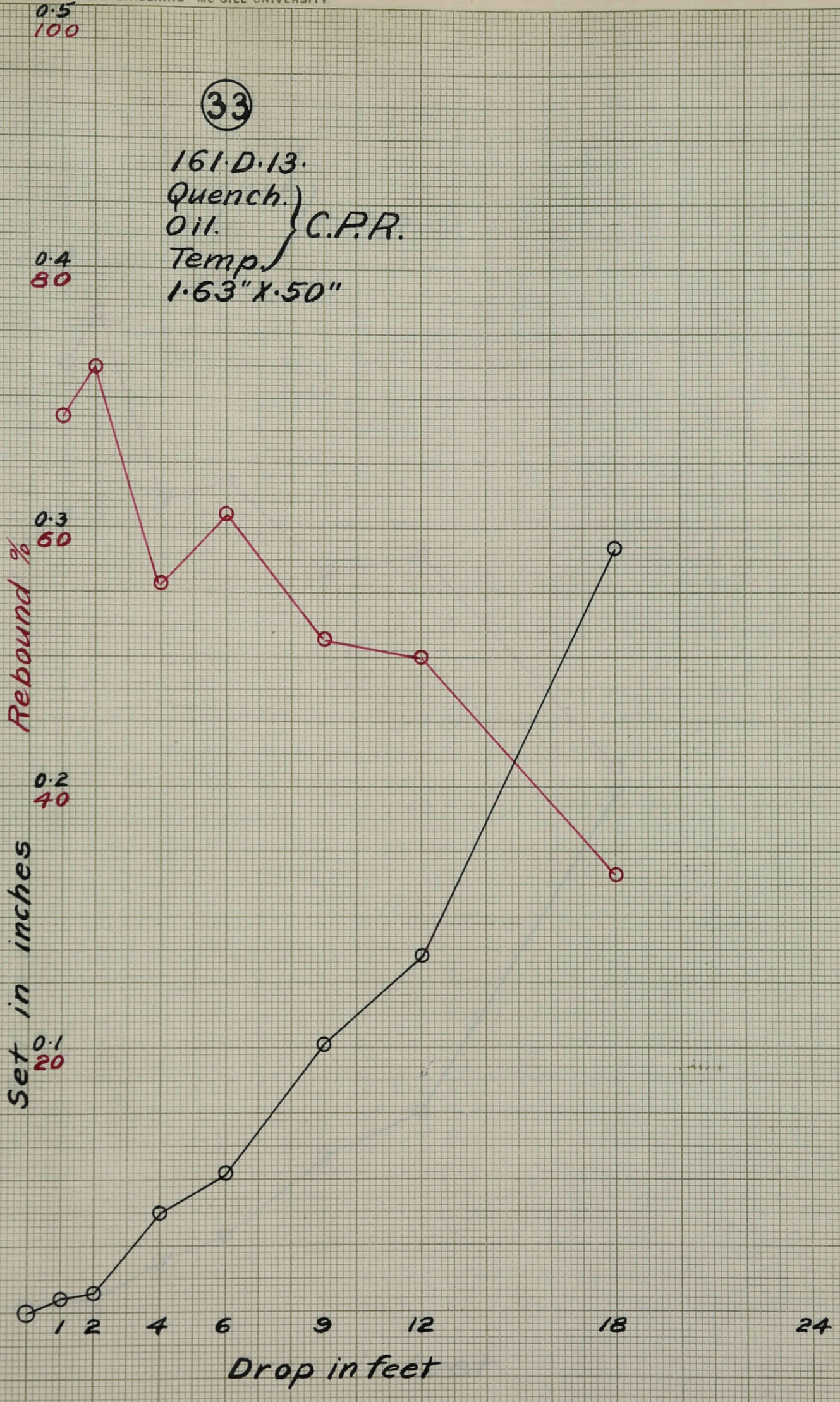
160·D·5·R
Quench. 775°C.
Oil. 60
Temp. 395 with 160·D·6·R·
1·60" X·48"

(32)

160·D·6·R
Quench. 797°C. Long hot.
Oil. 58
Temp. 395 with 160·D·5·R.
1·60" X·48"

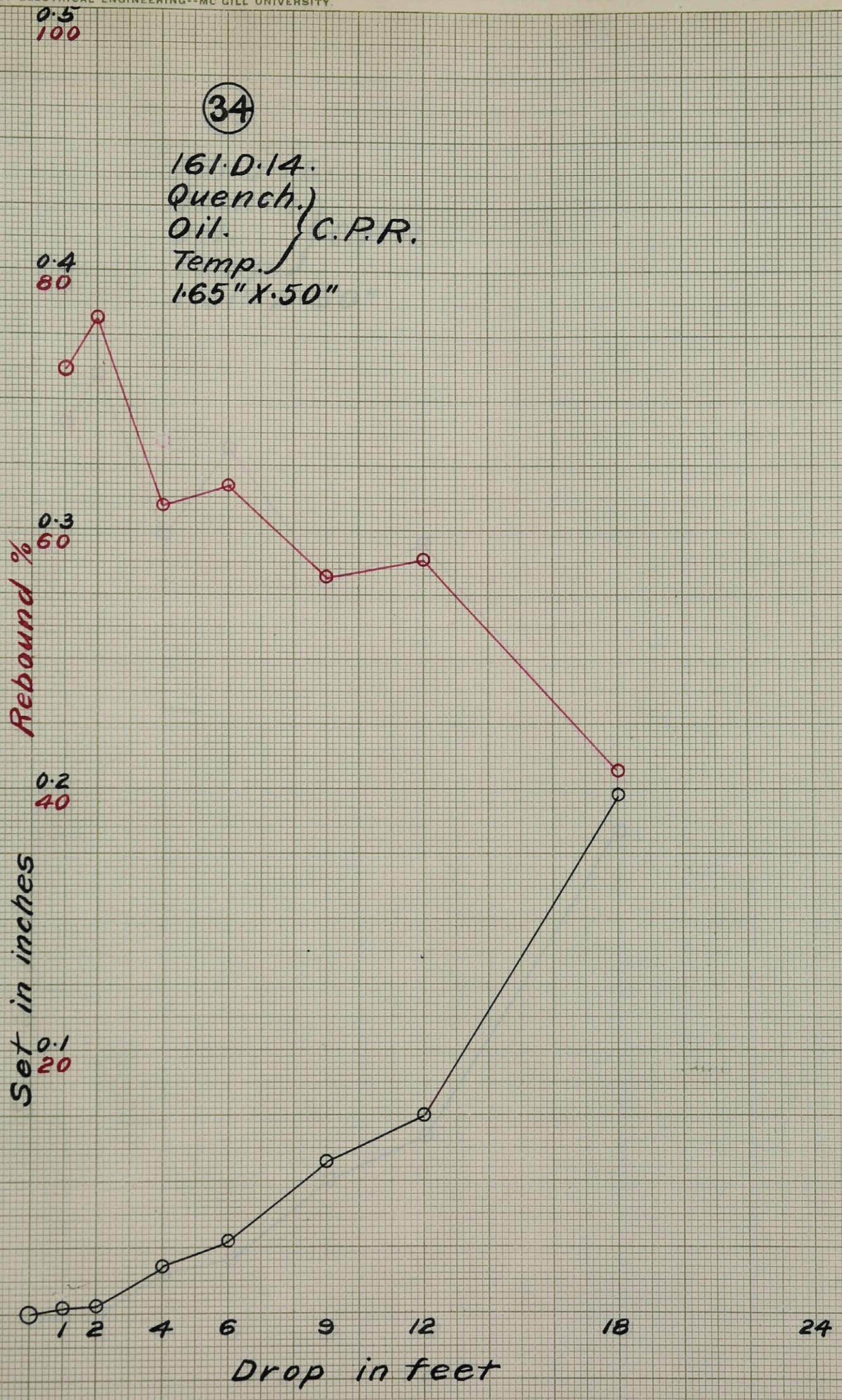
(33)

161·D·13·
Quench.)
Oil.
Temp.) C.P.R.
1·63" X·50"



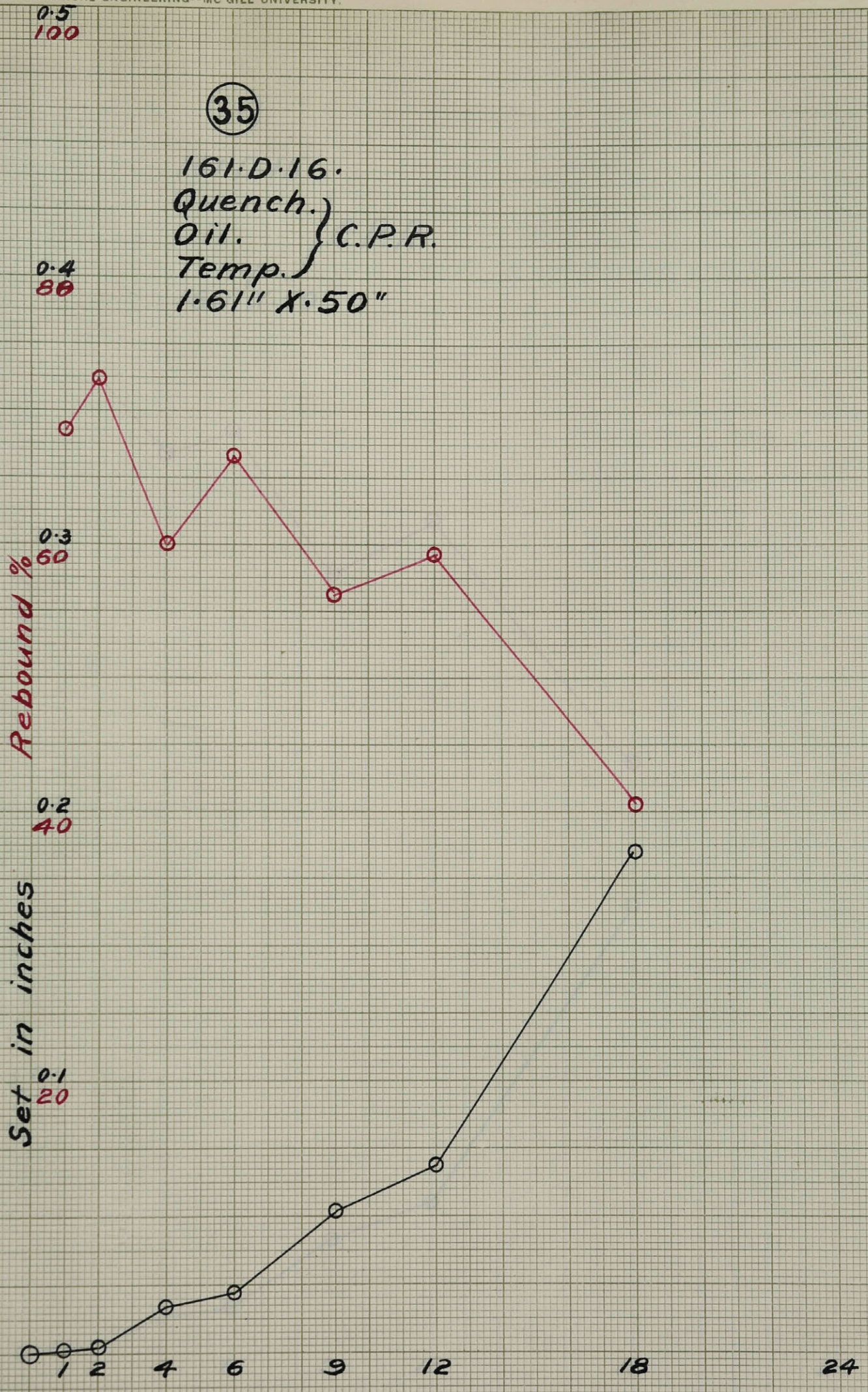
(34)

161·D·14.
Quench.)
Oil. } C.P.R.
Temp.)
1·65" X·50"



35

161·D·16.
Quench.)
Oil. } C.P.R.
Temp.)
1·61" X·50"



0·5
100

(36)

161·D·15·
Quench.)
Oil.
Temp.) C.P.R.
1·60" X·50"

0·4
80

0·3
60

Rebound %

0·2
40

Set in inches

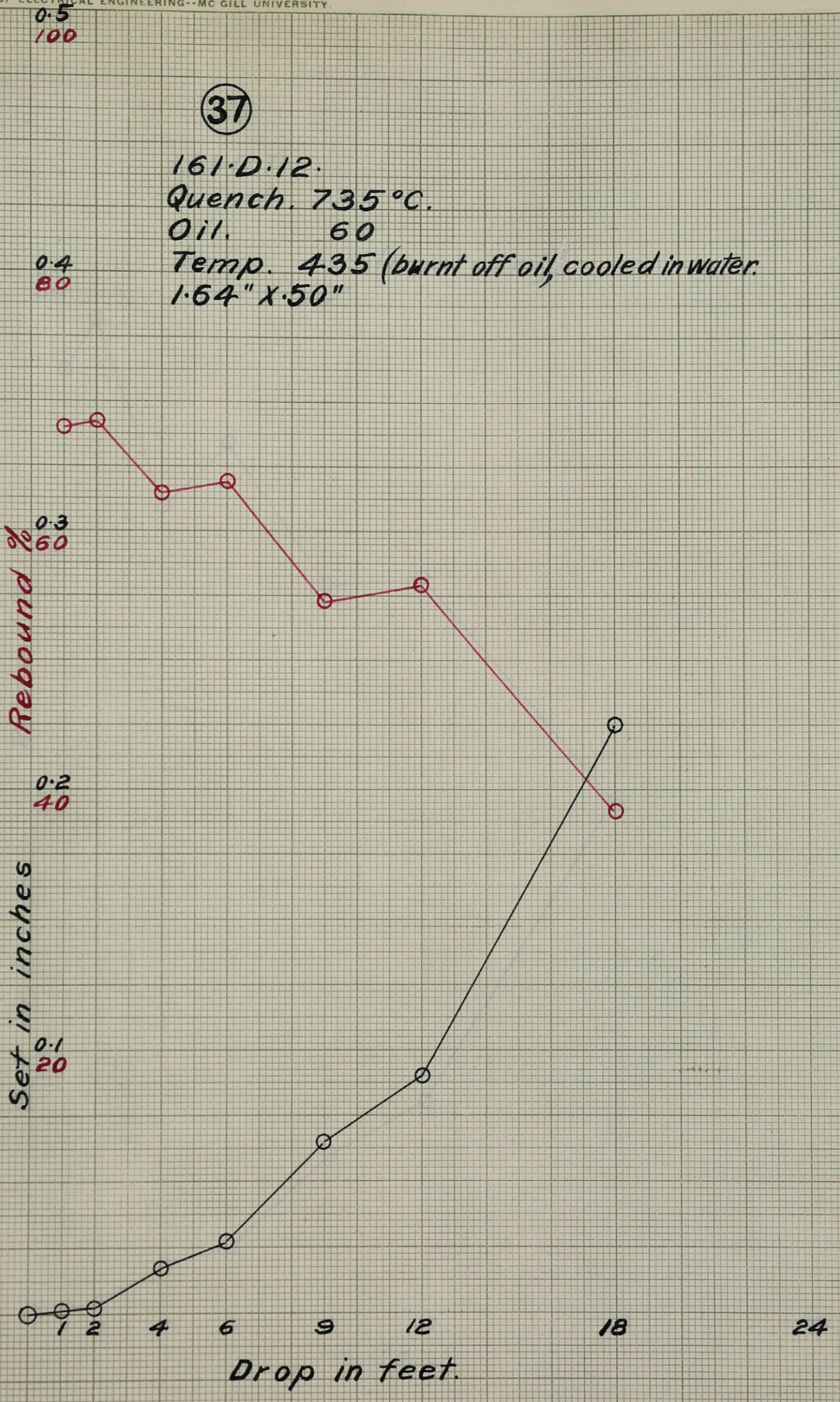
0·1
20

1 2 4 6 9 12 18 24

Drop in feet

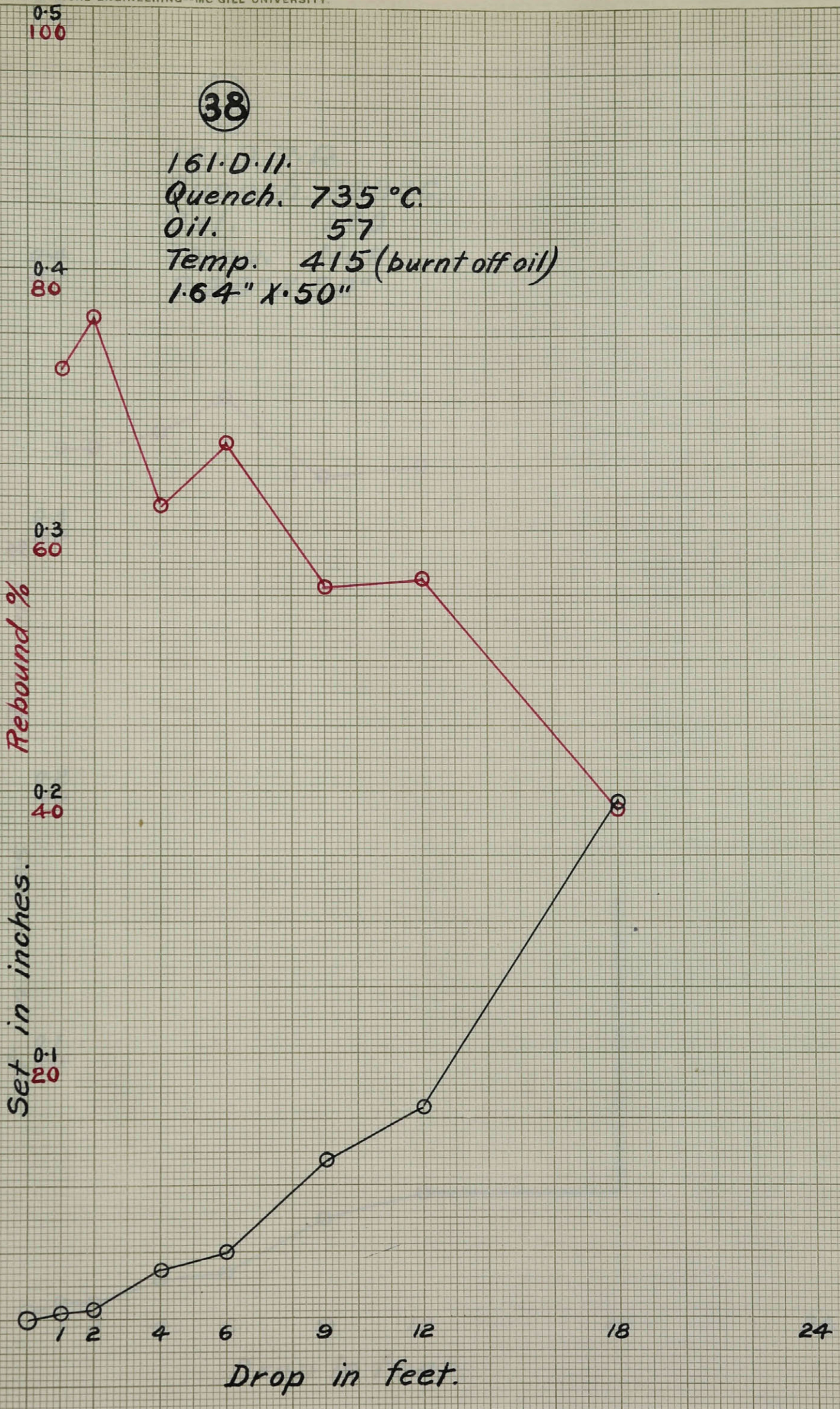
(37)

161·D·12.
Quench. 735 °C.
Oil. 60
Temp. 435 (burnt off oil, cooled in water.
1·64" x·50"



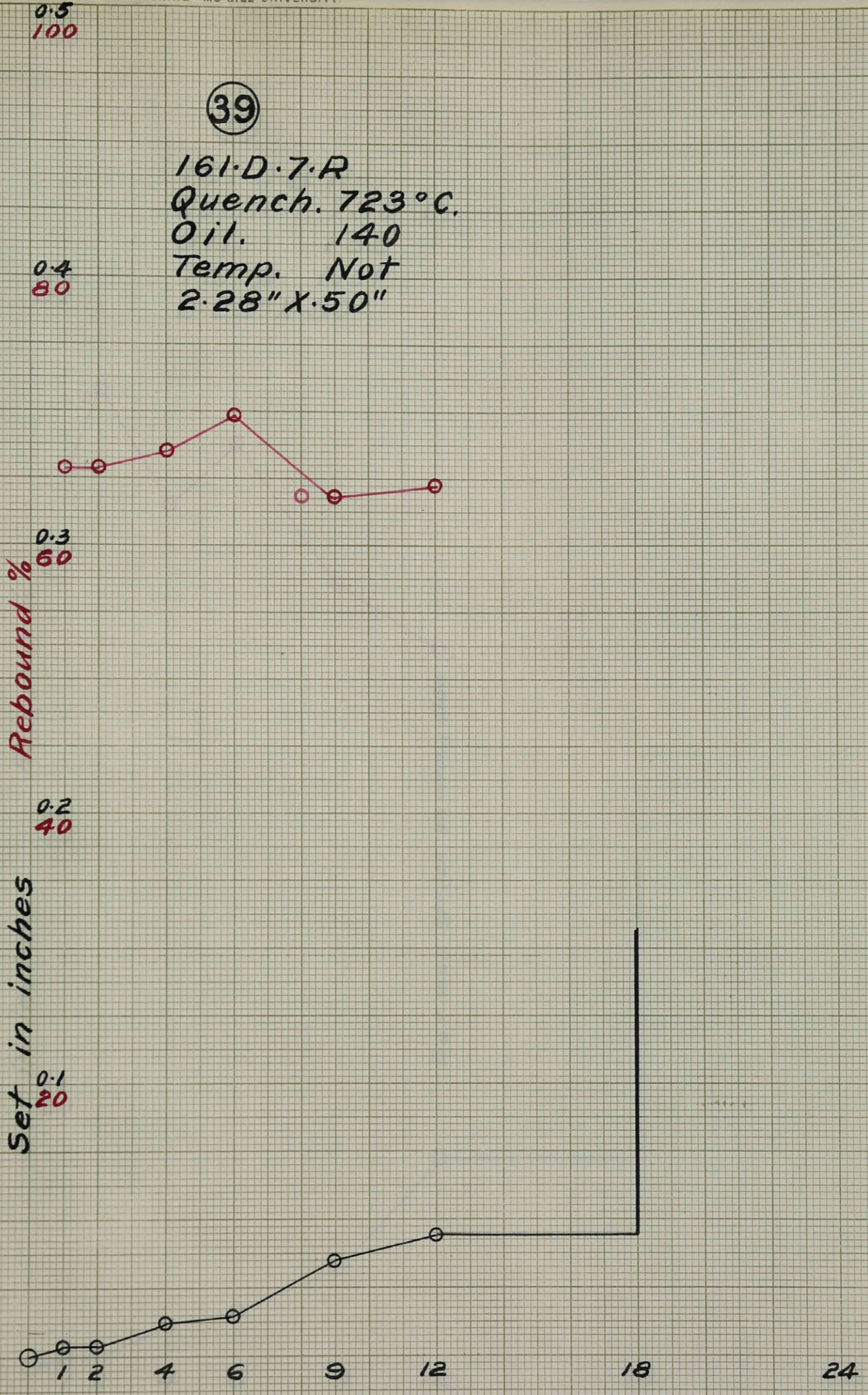
38

161·D·11.
Quench. 735 °C.
Oil. 57
Temp. 415 (burnt off oil)
1·64" X·50"



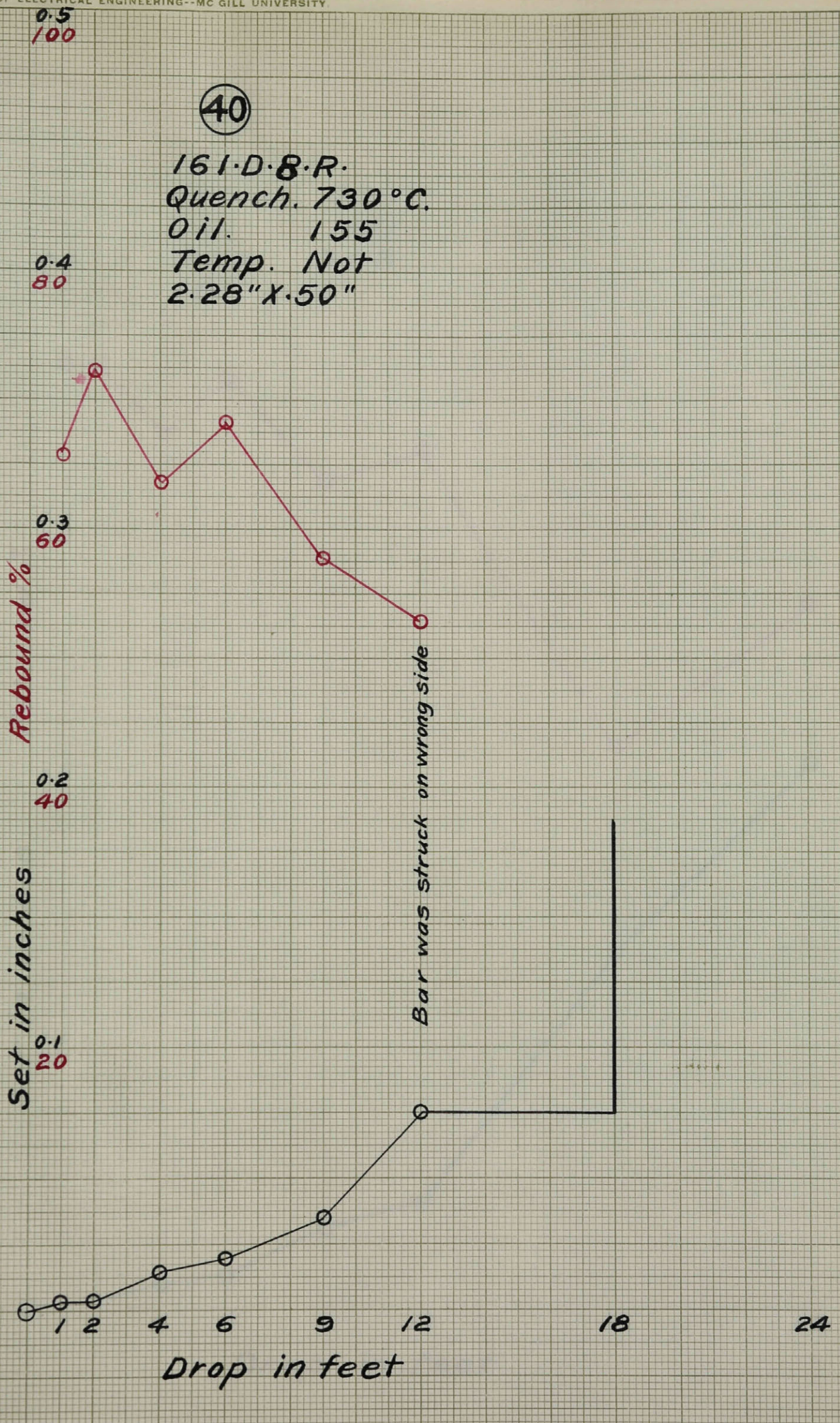
(39)

161·D·7·R
Quench. 723°C.
Oil. 140
Temp. Not
2·28" X·50"



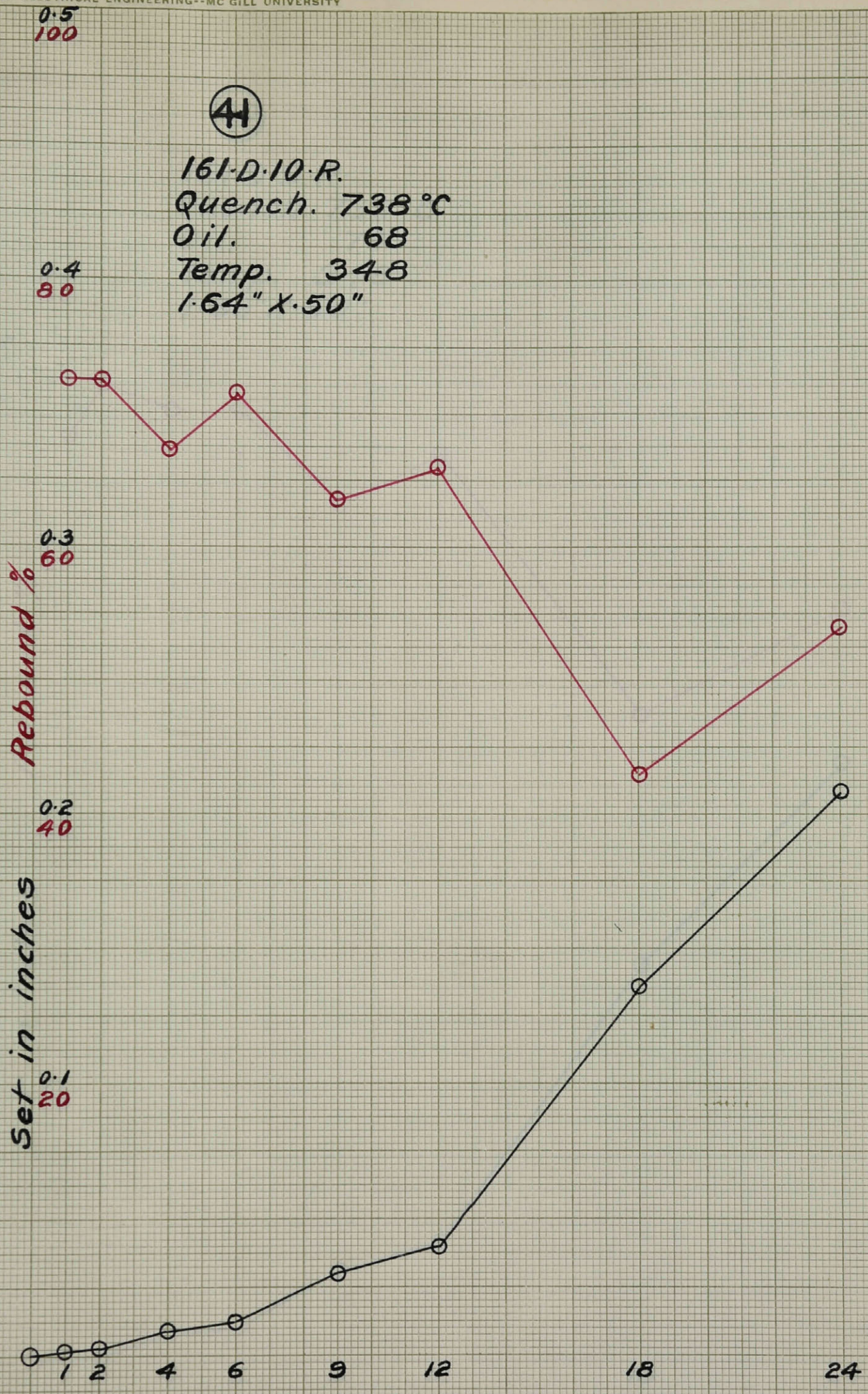
(40)

161·D·8·R·
Quench. 730°C.
Oil. 155
Temp. Not
2·28"X·50"



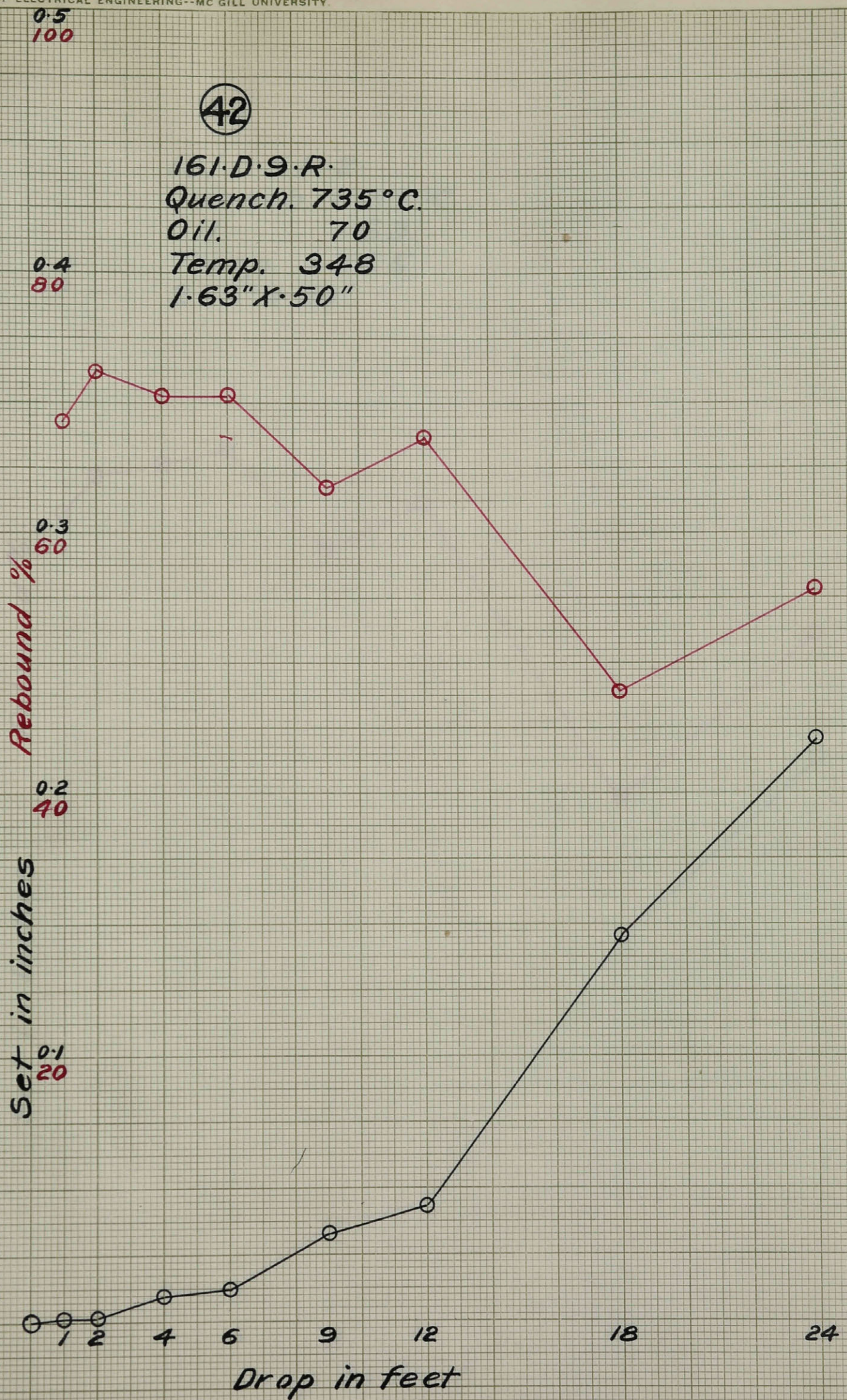
(41)

161-D-10-R.
Quench. 738 °C
Oil. 68
Temp. 348
1.64" X .50"



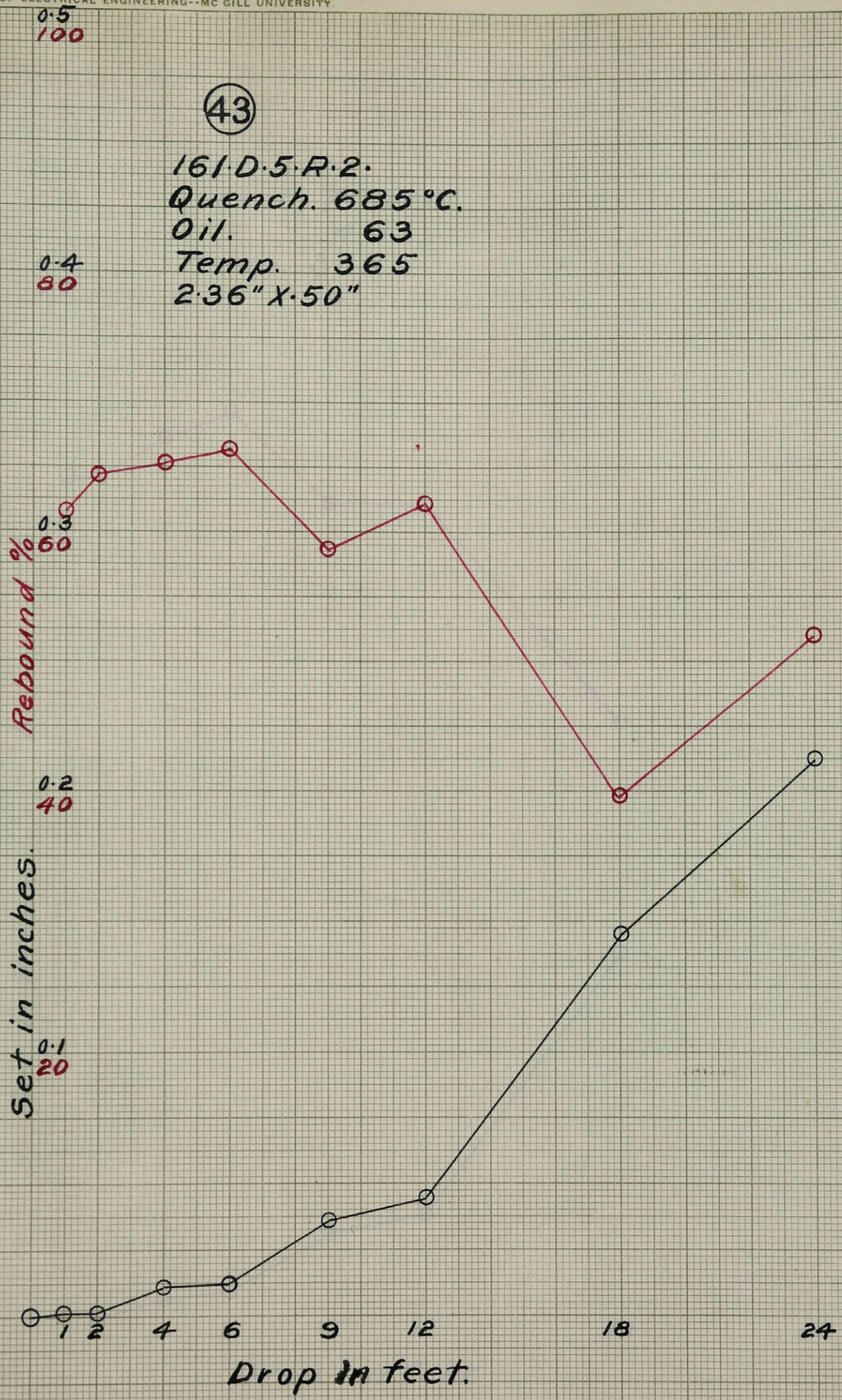
42

161·D·9·R·
Quench. 735°C.
Oil. 70
Temp. 348
1·63"X·50"



(43)

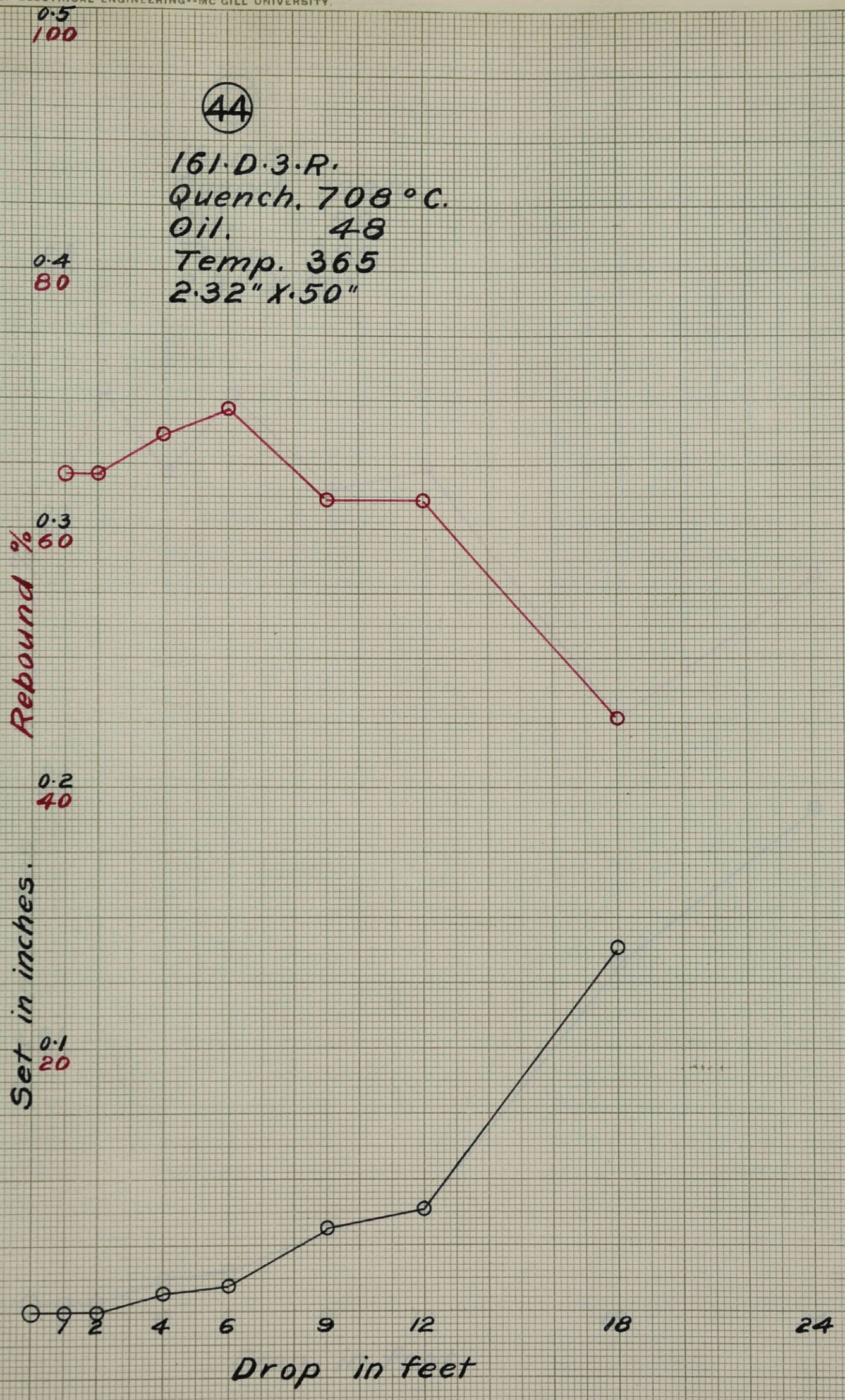
161·D·5·R·2·
Quench. 685°C.
Oil. 63
Temp. 365
2·36" X·50"



110

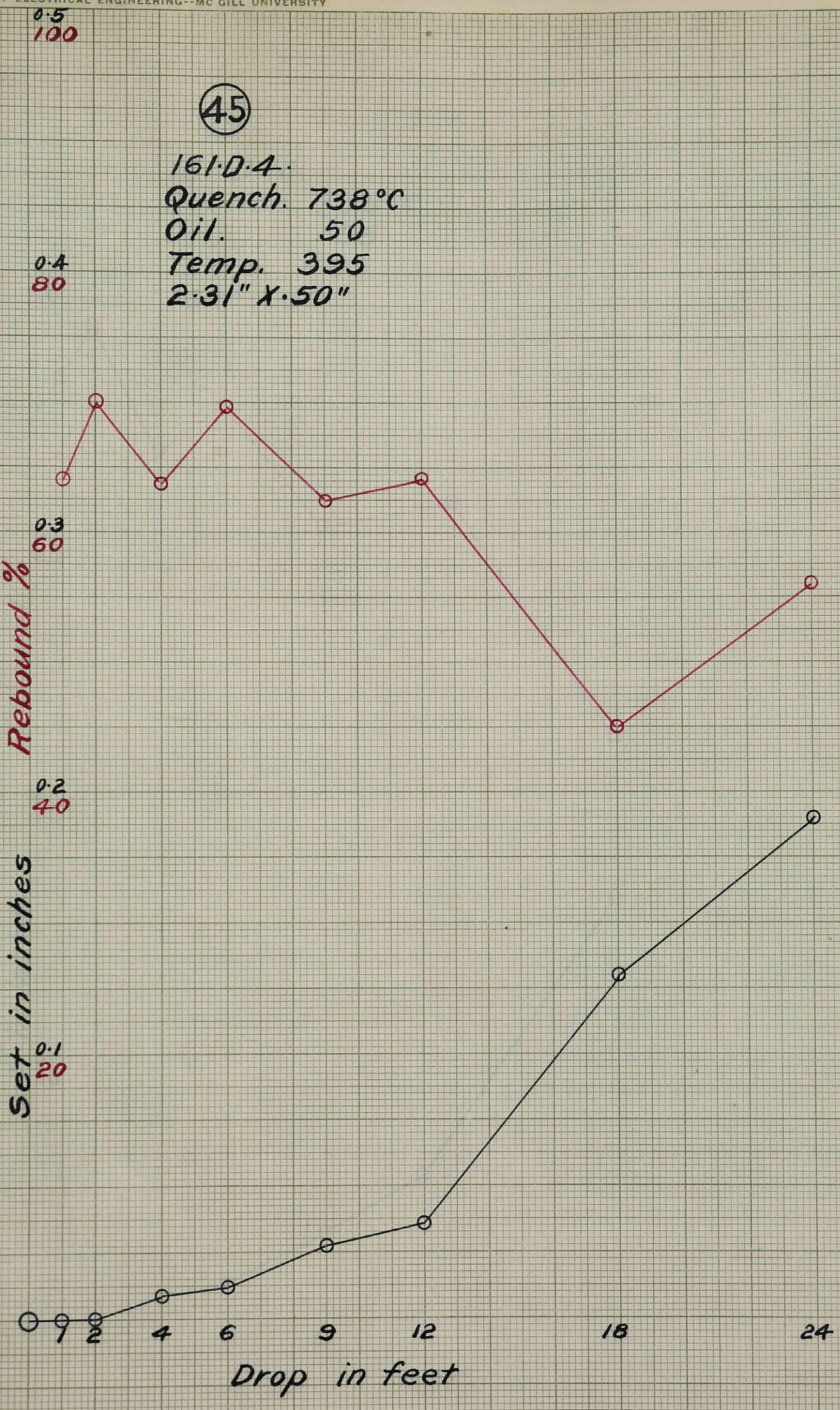
(44)

161·D·3·R·
Quench. 708°C.
Oil. 48
Temp. 365
2.32" X .50"



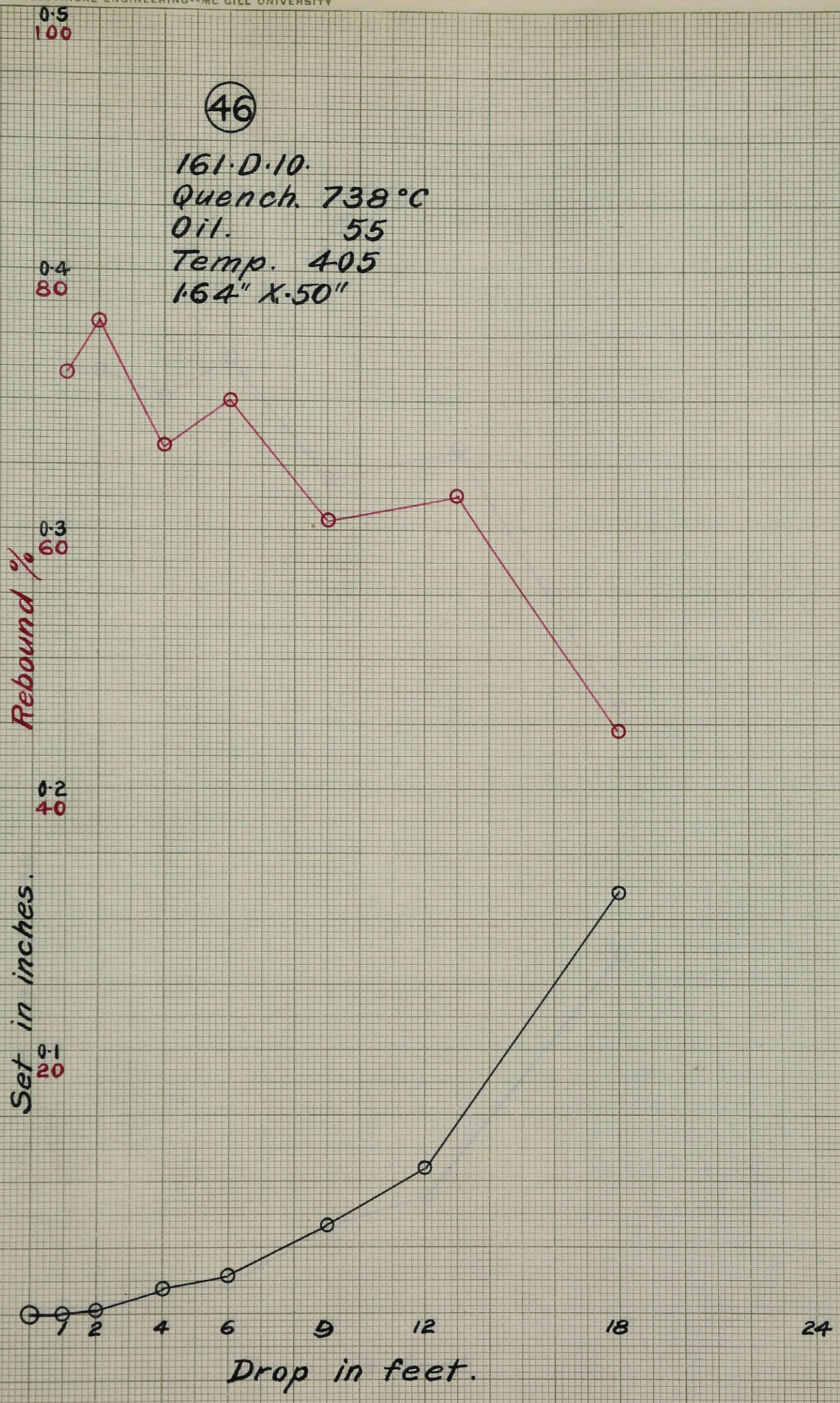
45

161·D·4·
Quench. 738°C
Oil. 50
Temp. 395
2·31" X·50"



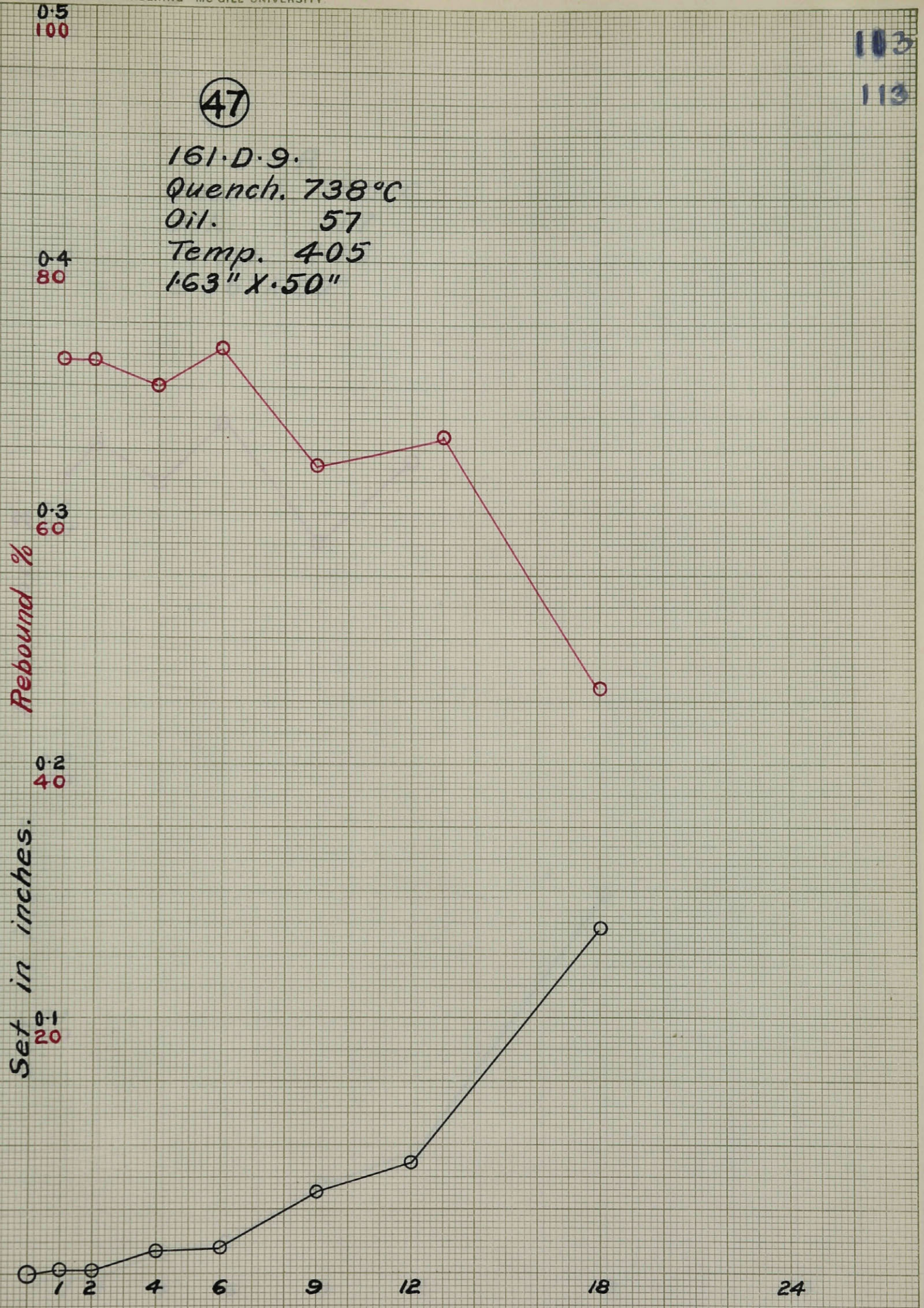
(46)

161·D·10·
Quench. 738°C
Oil. 55
Temp. 405
1.64" X .50"



47

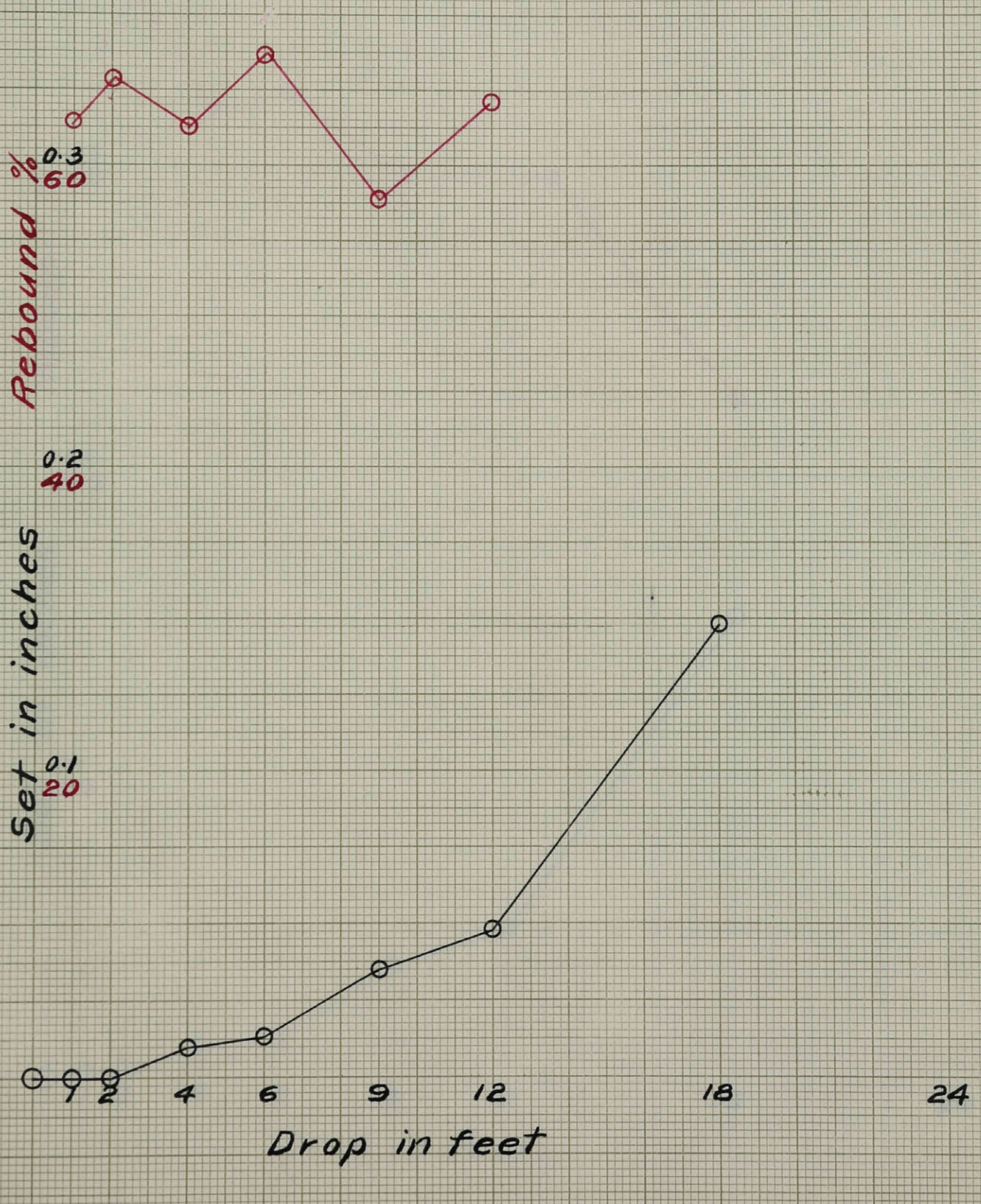
161·D·9.
Quench. 738°C
Oil. 57
Temp. 405
1·63" X·50"



0·5
100

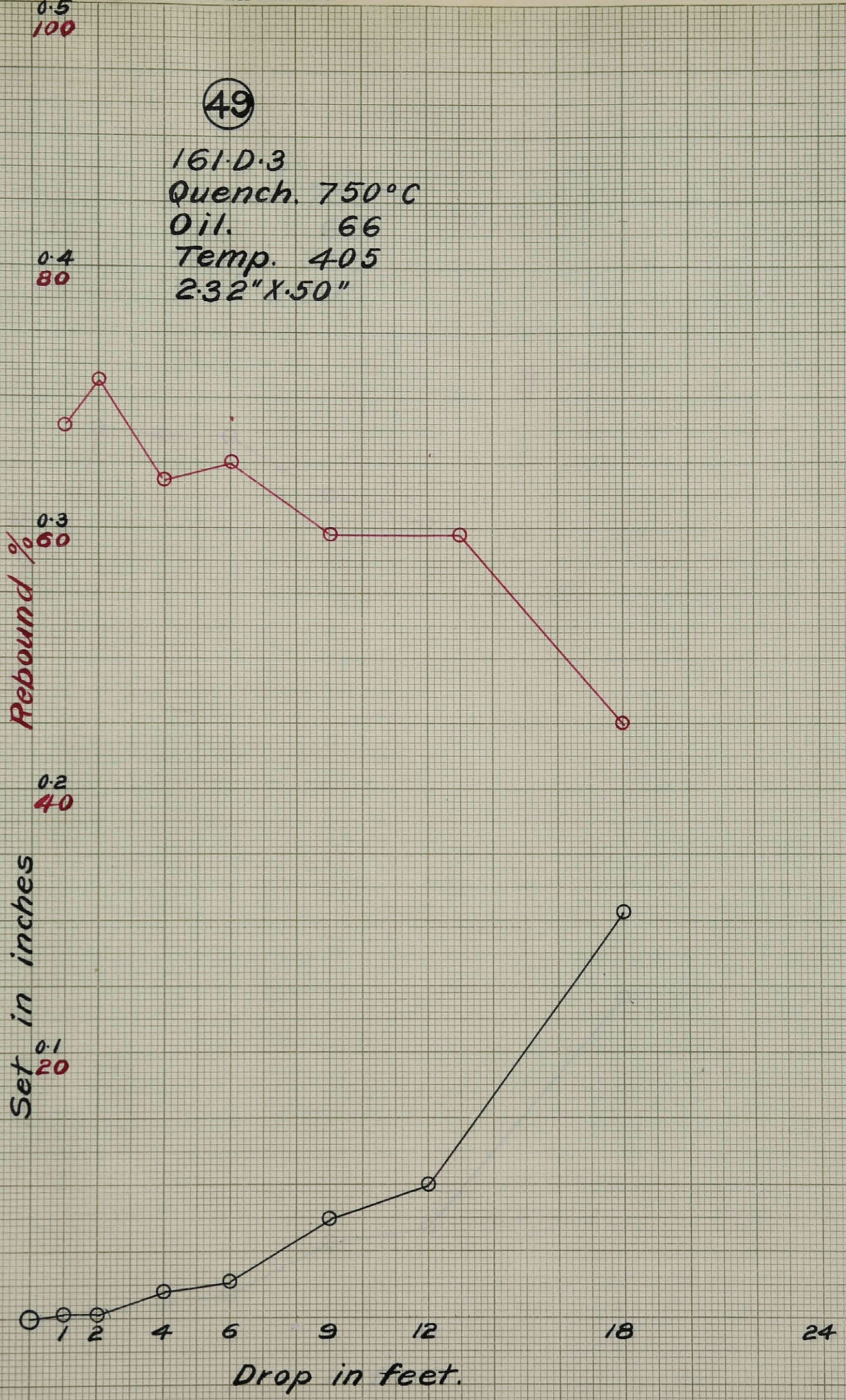
(48)

161·D·5·R
Quench. 755°C.
Oil. 17
Temp. 405
2·36"X·50"



(49)

161·D·3
Quench. 750°C
Oil. 66
Temp. 405
2·32"X·50"

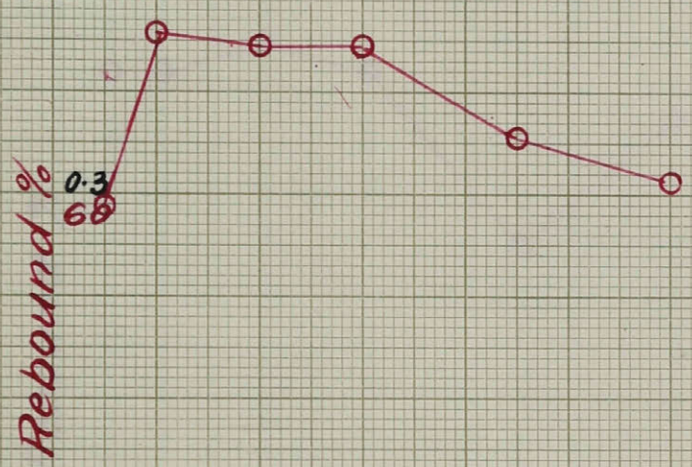


0·5
100

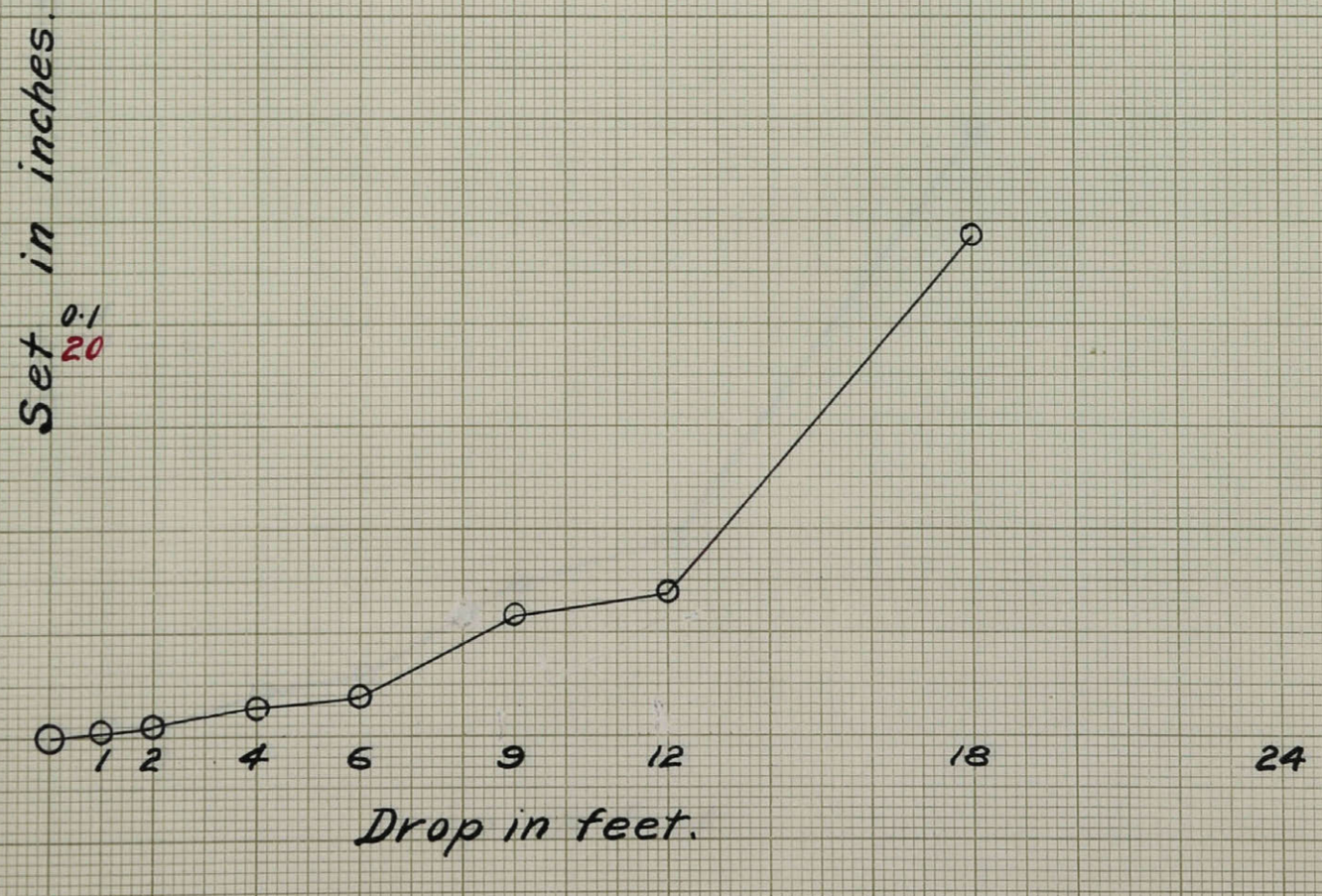
(50)

161·D·6·
Quench. 753°C.
Oil. 65
Temp. 395
2·33" X·50"

0·4
80



0·2
40

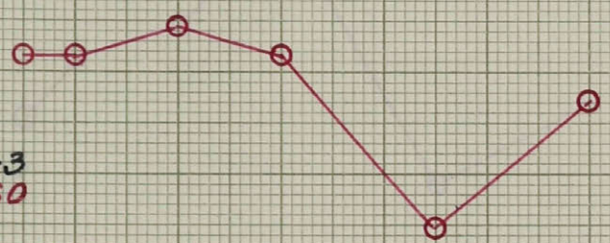


0·5
100

(51)

161·D·8.
Quench. 723°C
Oil. 70
Temp. 395
2·28" X·50"

0·4
80



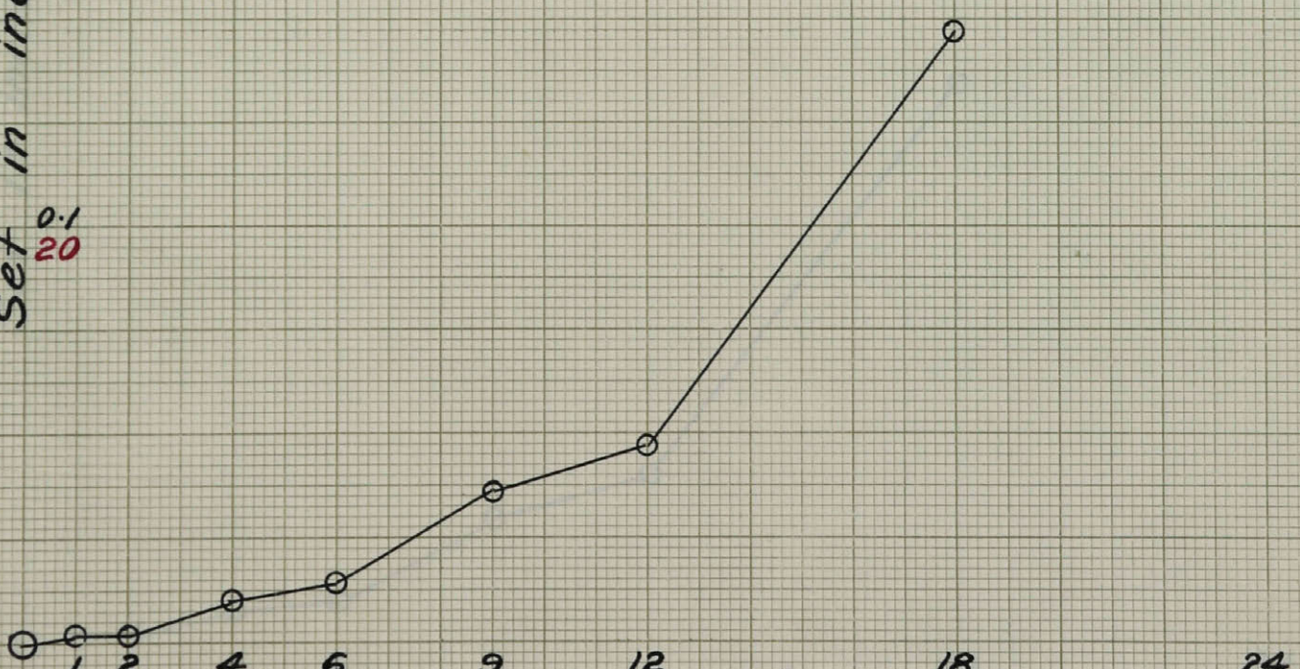
0·3
60

Rebound %

0·2
40

Set in inches.

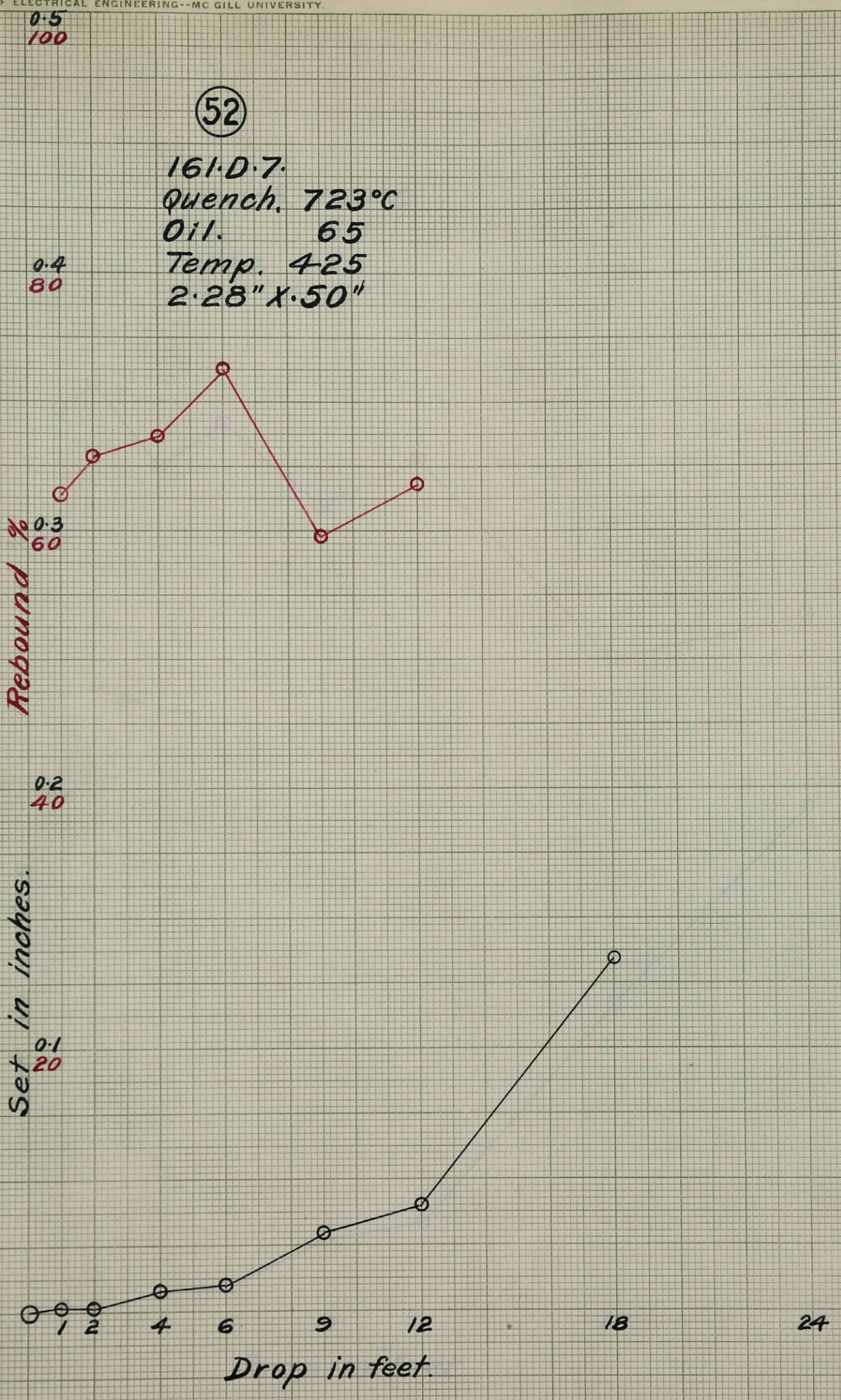
0·1
20



Drop in feet

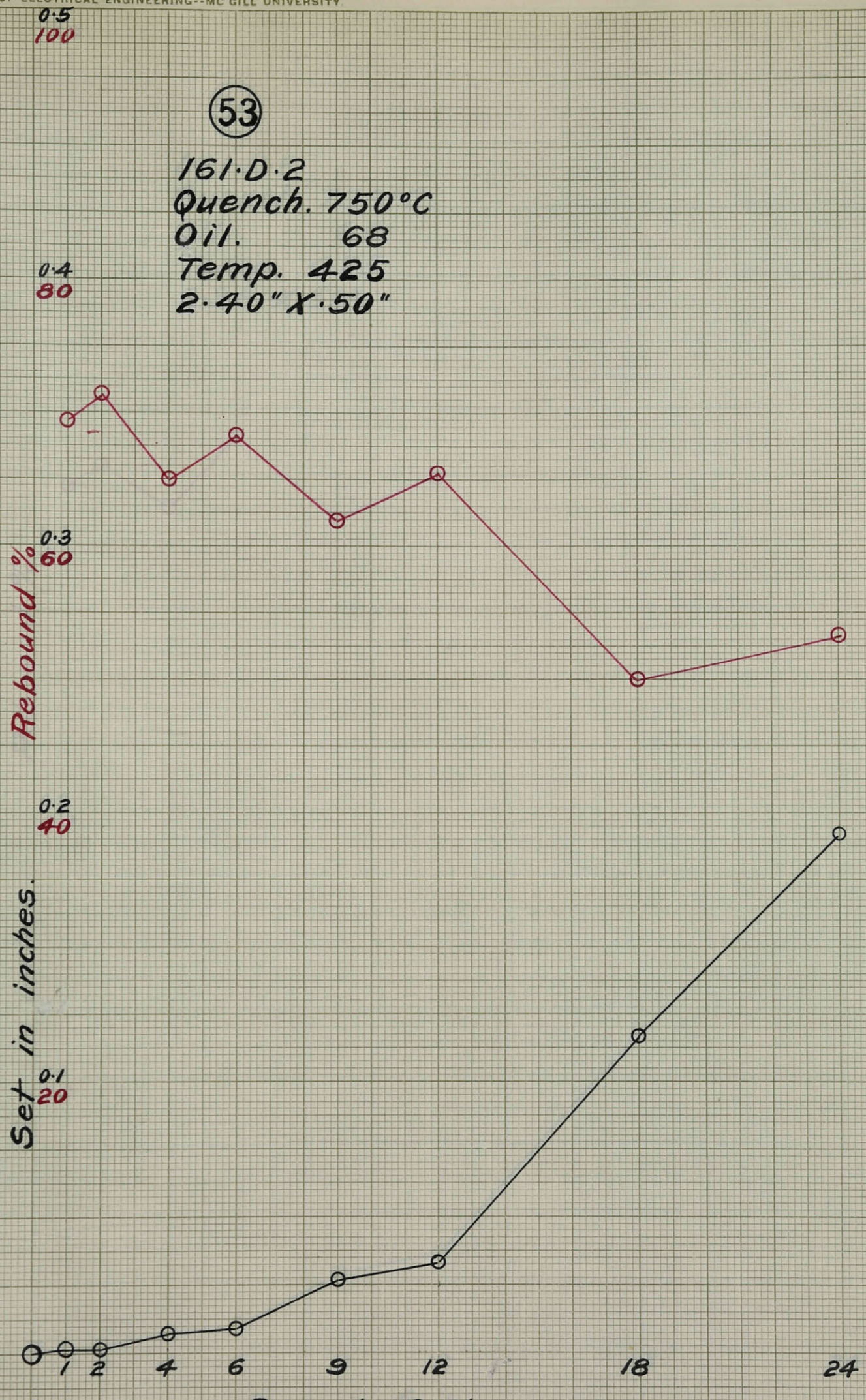
(52)

161·D·7·
Quench. 723°C
Oil. 65
Temp. 425
2·28" x·50"



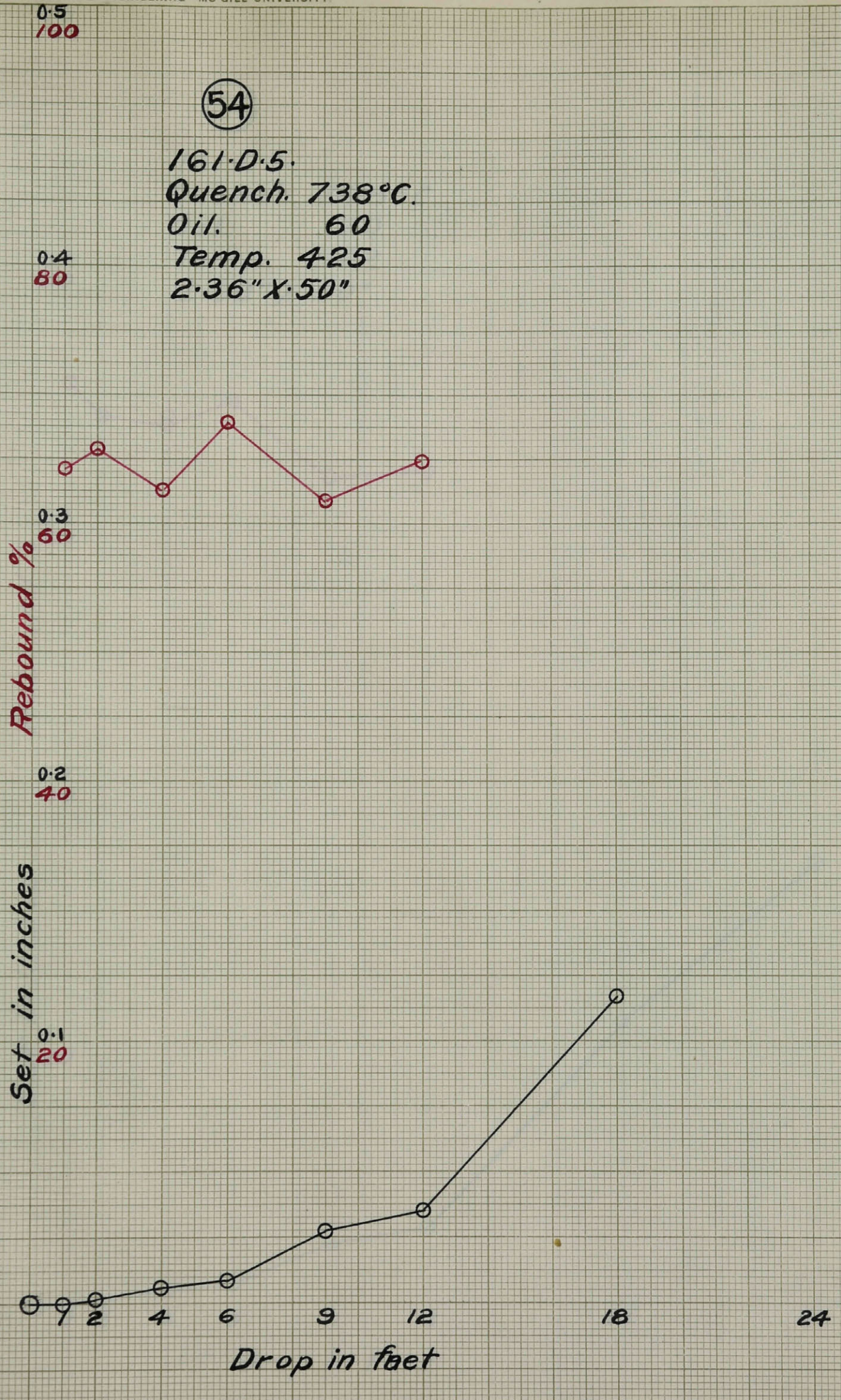
53

161·D·2
Quench. 750°C
Oil. 68
Temp. 425
2·40" X ·50"



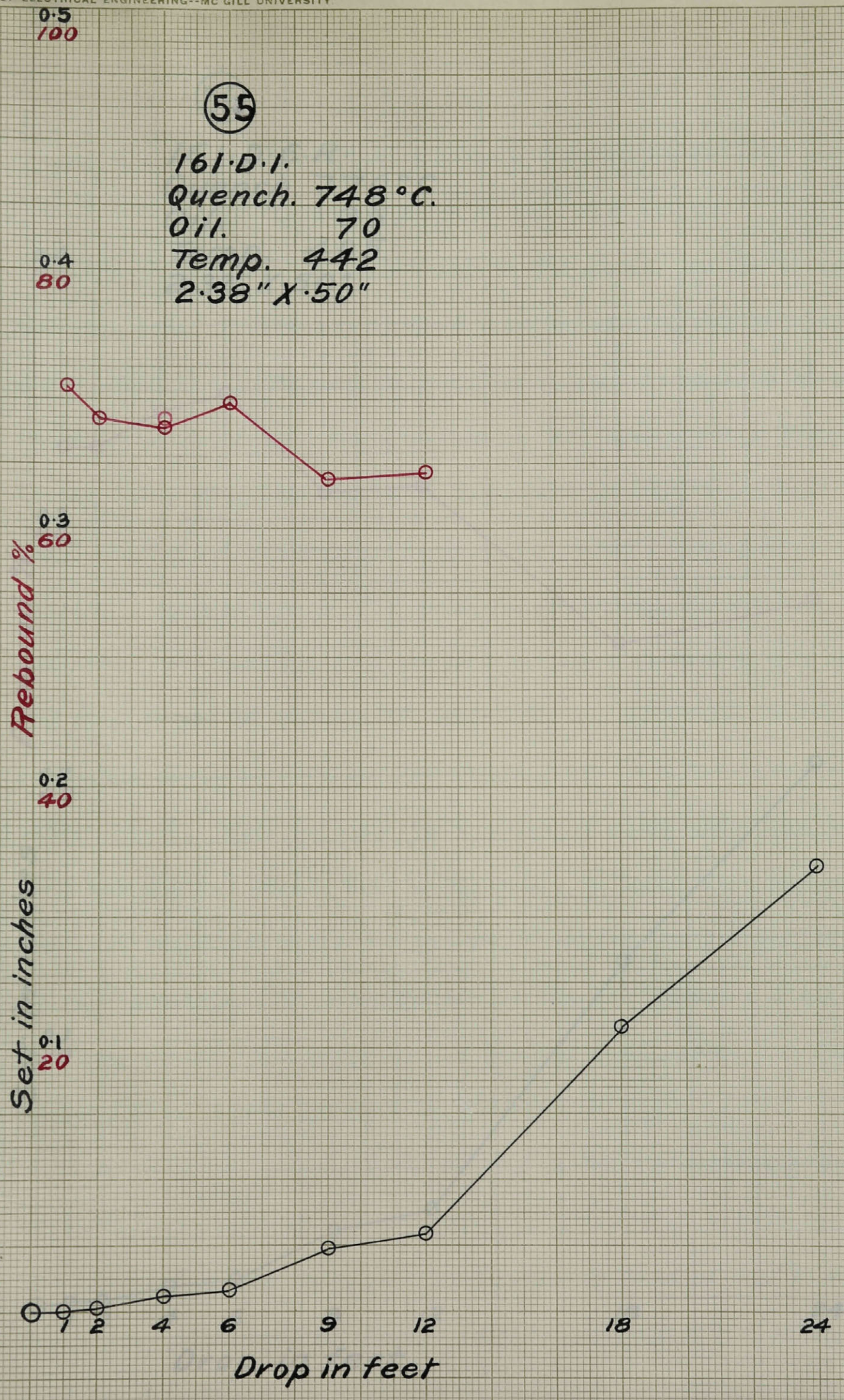
(54)

161·D·5·
Quench. 738°C.
Oil. 60
Temp. 425
2·36" X·50"



55

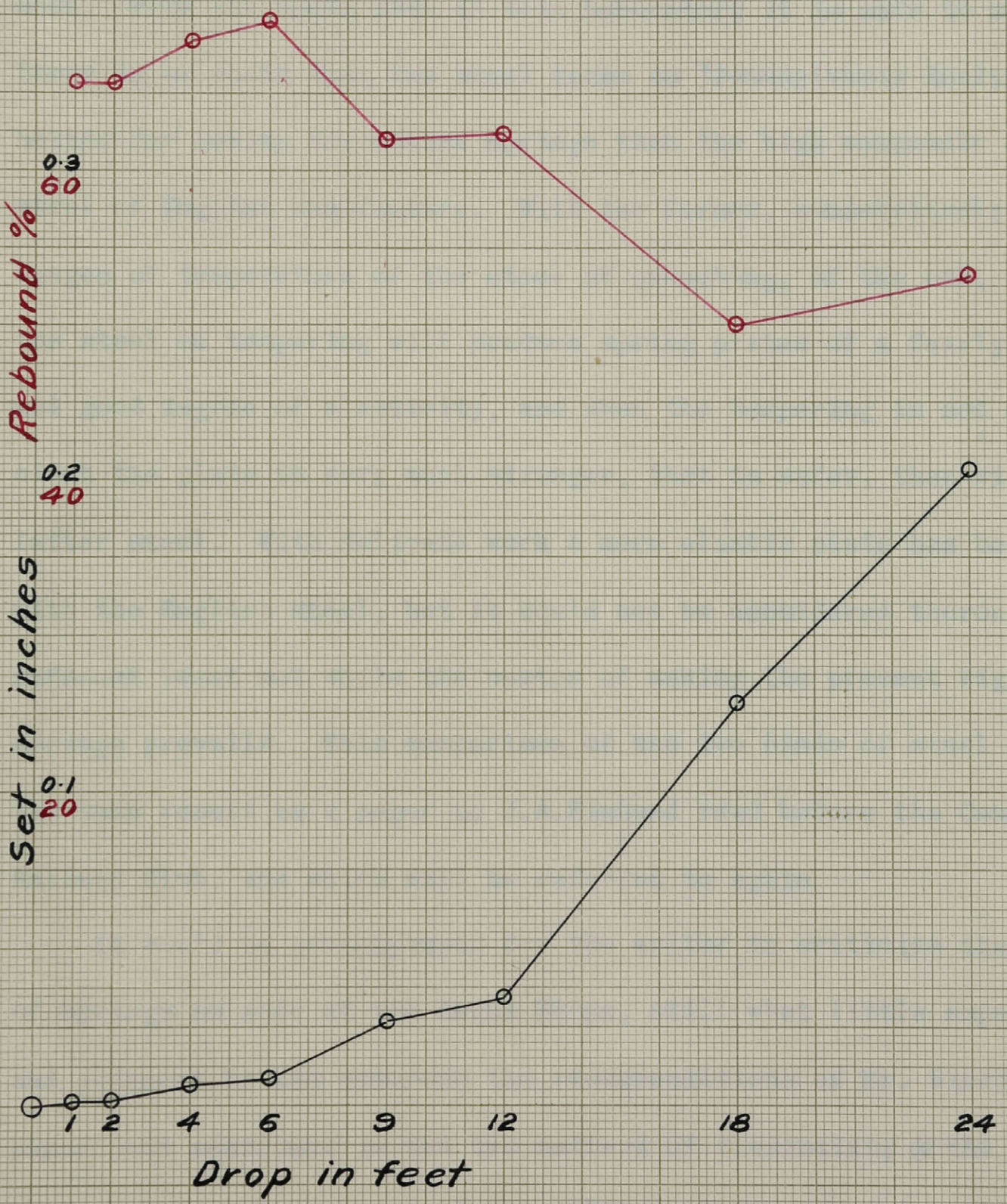
161·D·1.
Quench. 748°C.
Oil. 70
Temp. 442
2·38" X ·50"



0·5
100

(56)

161·D·6·R.
Quench. 770° C.
Oil. 35.
Temp. 405
2·33" X·50"



REPORT ON THE MAKING OF LOCOMOTIVE SPRINGS

AT THE ANGUS SHOPS OF THE C.P.Ry. Co.

The thing of first importance is the steel, and it is practically the only point on which a definite recommendation can be confidently made. From the tests made in this Laboratory it is safe to say that there is no doubt that the steel known as "Pennsylvania Analysis" is better for making locomotive springs than the high manganese spring steel of English manufacture. With the former, comparatively wide ranges of temperature of the steel at quenching, of the oil, and of the steel on tempering will produce spring plates of a fairly uniform and good degree of elasticity, and when the tempering is not sufficient the plate is very much stronger, that is safer, than with the latter steel. With delicate work a more elastic plate has been made with the English steel, but it could not be considered thoroughly safe--at least not while the custom of making the present rigid springs prevails. This comparison of the two kinds of steel shows the same result as a paper by J.A.Kinkead read before the Canadian Railway Club, and which will be referred to again.

It would be presumptuous for the writer to criticize the design of springs as made at the Angus Shops, still what little experience and judgment he has endorses the recommendations of Mr. Kinkead in paper just mentioned in the two matters of flexibility of the assembled spring, and accuracy of the fitting of the component plates to

to each other. The writer was told by the foreman that a back-plate, 46" between bearings, had its camber increased by 1 1/4" by the buckle; it required 575 lbs. to do this in the testing machine with a plate picked at random, and 1300 lbs. to increase the camber by 1 1/8" when it was backed by the next two plates from the same spring. In another case, also taken at random, the outside plates of a spring were 10" apart at the centre when fitted for putting on the buckle (They had been partly squeezed and released) When squeezed close, ready for the buckle, the outside plates were only 7 1/4" apapt, a difference of 2 3/4". This does not necessarily mean that the camber of the back-plate had been increased by more than 1 1/4", as the 2 3/4" space, although mostly between the longer plates, was distributed, and some of the shorter plates would be straightened by putting on the buckle.

The question "How may the tempering of the steel be improved?" is a very difficult one. It seems that when springs fail in service there is no place where the plates are much more liable to break than another. One man says: generally the 3rd or 4th plate from the back, and near to the buckle. Another says: about as often a short plate, or near the end of any plate.

It has been suggested that probably a plate breaks because it is the only properly tempered plate in the spring, and ~~that~~ the others bend till the good one is too greatly overloaded. This seems

reasonable, because in the method of hardening and tempering used at the shops the errors most likely to be made are: quenching at too low a temperature and tempering to too high a temperature. Four test plates each of ~~both~~ the American and the English steel were tempered and sent to this Laboratory. All the pieces of English steel were much too soft. Of the American steel, three were fairly elastic and the fourth was soft. Thus it would seem that in service a plate breaks because it is relatively rather than absolutely brittle.

Now let us consider methods of regulating these temperatures.

A magnetic indicator is out of the question. It would be very difficult, if possible at all, to arrange anything automatic—anything that would not need the full attention of a man, as does ~~like~~ a suspended needle. The return of magnetism in the plate as a whole, or any considerable part of it, cannot be used as it would then be far too cold. Nor can the cooling ends be used because they are generally magnetic when the plate comes from the bending bench, especially if the ends are thinned. Another ever present objection is that a flake of scale, loose and quickly cooling, can give a wrong indication with a magnet.

A possibility in the way of apparatus is as follows: a thermocouple in the end of a post, that, by a spring, would rise according to the size and shape of the plate and press the thermocouple against it; a reflecting galvanometer in a safe place, and a scale, say over the oil tank, where the workman could watch the retreating spot of

light as he attended to the next plate, and quench the first one as soon as it cooled to the correct temperature. This would be convenient and would give perfect accuracy in the quenching temperature. Objections are: the cost of galvanometers for the several oil tanks; the necessity for testing and adjusting them--but this would exist to at least the same extent in any system of temperature regulation. The chief objection is that the system does not so far afford means for regulating the tempering temperature. Baths of lead, with automatic temperature regulation, could be used for this; but the system would then be rather complicated, and there are other objections to the use of baths of molten metal, such as loss of metal by oxidation and spilling, and difficulty in securing proper immersion of the spring plates. For similar reasons, chiefly its cumbersomeness, a set of six more furnaces with temperature and now also time regulation, would be out of the question.

A final alternative would be to instal a completely different system to the one at present in use. It is not thought necessary to go into the details of such a system an an accurate quantitative basis at present, but an outline of it would be as follows:

A heating furnace, preparatory to cambering.

A mechanical bending machine.

A furnace with temperature and time regulation to bring the plates to the proper quenching temperature.

Oil quenching tanks, water-cooled.

A furnace with temperature and time regulation to properly temper the plates. Possibly this furnace would be fitted with a conveyor that would carry the plates through in the correct time, as the temperature would not be very high.

Such a system as this would in any case be much more economical of fuel and labour than the present one. With properly arranged work, a machine of the "Bulldozer" type could be used for cambering, changing forms occasionally, and bending special or odd springs by hand as at present. The plates could be accurately and instantly bent at a lower temperature than at present, quenched at the correct temperature and tempered to the correct temperature. Objections are: the cost of making so radical a change, and, it is believed, considerable difficulty in accurately regulating the second and third furnaces. A galvanometer with leads to thermocouples at the outgoing side of these two furnaces would need to be installed, then an occasional plate could be used to check their working.

Respectfully submitted

Gordon Sproule.

The following is a list of quantities supplied by the foreman in charge of the locomotive spring making. The numbers are plates handled per furnace per ten hours, when making springs from the corresponding size of steel.

Engine springs.

5" X 1/2"	120	5" X 7/16"	120
4" X 1/2"	180	4" X 3/8"	180
4 1/2" X 3/8"	180		
3 1/2" X 1/2"	200	3 1/2" X 3/8"	200

Engine Truck springs.

3 1/2" X 1/2"	140

Elliptic Tender springs.

3 1/2" X 3/8"	200	3 1/2" X 7/16"	200

Long Tender springs.

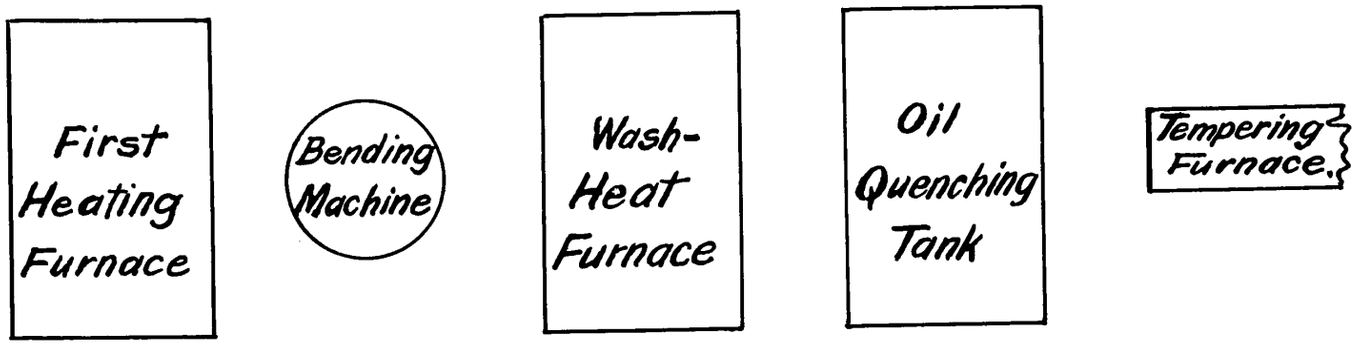
4" X 1/2"	100.

These figures are estimates in round numbers. The length of plates varies from about 63" down to about 12", the average being perhaps 30". The men are paid by the number of plates tempered.

PROPOSED SCHEME FOR SPRING MAKING PLANT.

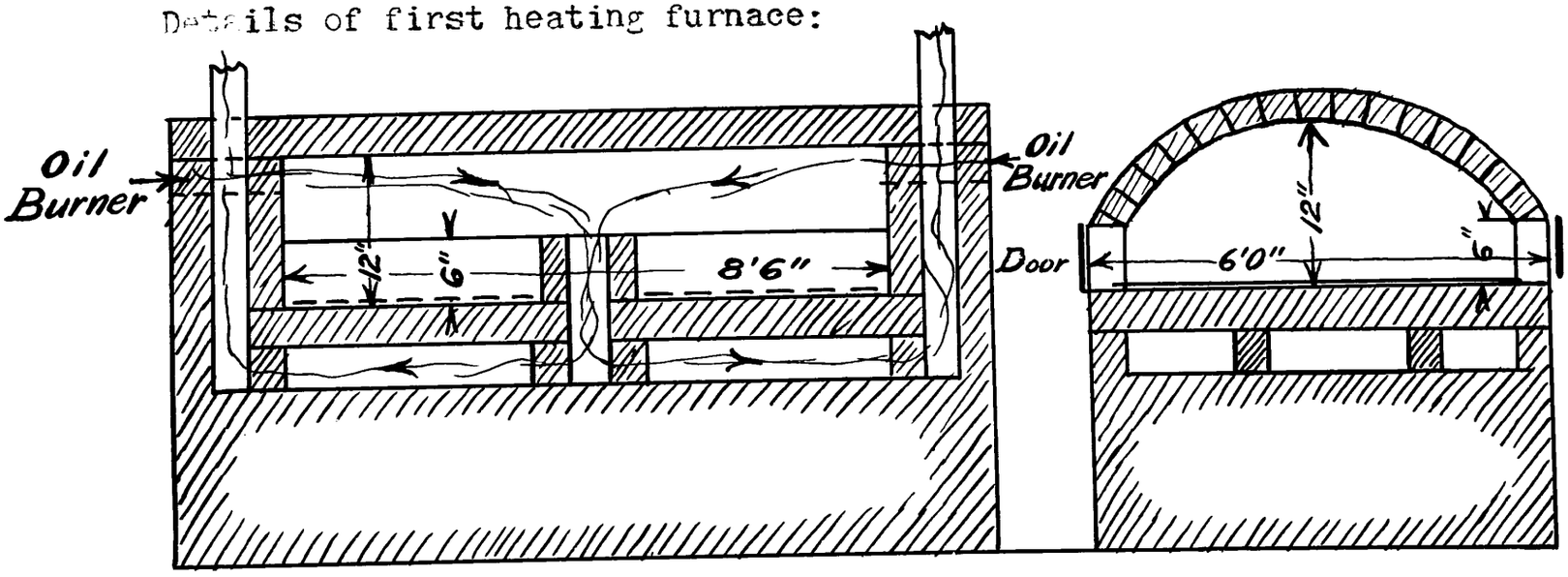
Suppose the maximum number of plates to be handled in ten hours to be 1000, equals 100 per hour. Max. length, 63". Max. width, 5".

Diagramatic view of scheme:



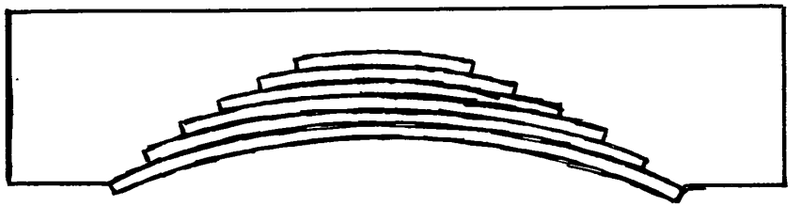
First furnace: Plates take ten minutes to heat, so there will be about 17 plates in the furnace at a time. 17 X 6" = 8'6" the necessary length of the furnace; the width, to take the plates across it, would be 6'. As the plates go in straight, the furnace can be quite low, say 6" high at the sides and 12" high at the middle.

Details of first heating furnace:



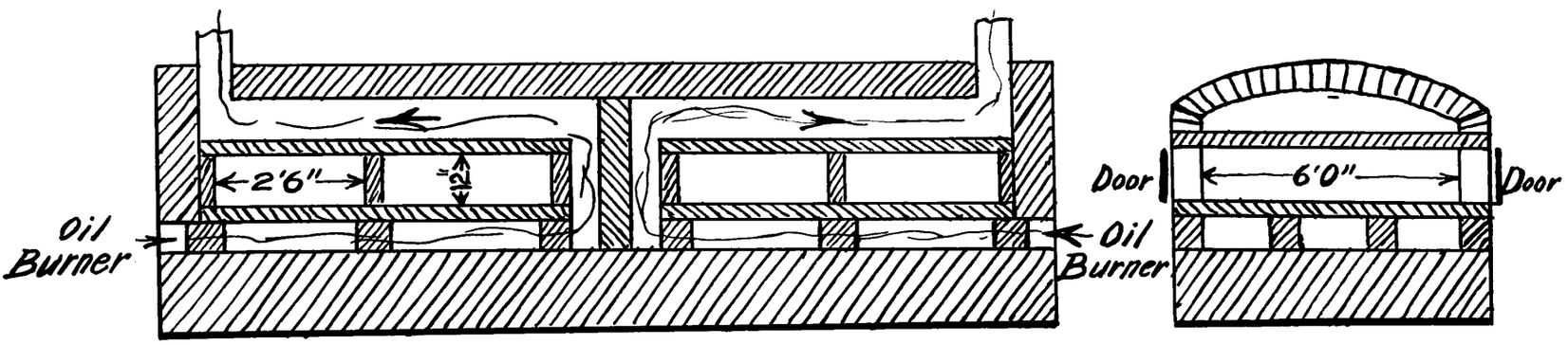
One man could easily feed the plates into this furnace, and two men on the other side could take them out, camber them in a machine, and feed them into the wash-heat furnace.

Cambering machine: A machine of the "Bulldozer" type is suggested. A suggestion for a die is shown in the sketch; when bending the longer plates, the operator would fill up the die with shorter plates already made. Small numbers of special, odd, or repair job springs would have to be bent by hand as at present. The number and variety of types of springs to be made is the only real objection to the installation of a machine bender.



Second furnace: A wash heat furnace, kept by pyrometer as nearly as possible at the right temperature at which the plates should be quenched in the oil. This furnace could be smaller than the first, as the time in it would be only about 3 to 5 minutes, but the construction would be more elaborate in order to secure a perfectly even and constant temperature; the foreman in charge of the spring making could attend to the regulation of this furnace, and the tempering furnace to be described.

Details of wash heat furnace;



Quenching tank: A tank about 6' wide X 9' long, containing the usual straw seal oil, about 3' deep. Cooled by water pipes along the sides, and stirred by streams of air rising from the bottom as at present, but along the sides, outside the cooling pipes. The spring leaves would come directly from the wash heat furnace, and be lowered into the oil by a sort of stirrup, the coldest plate then being taken out.

Tempering furnace: Fired preferably by gas; accurately regulated by pyrometer. The plates should be in this furnace 5 or 10 minutes. Suppose four plates abreast on the travelling floor, equals 25 plates per hour on end; this, with a max. length of 5' necessitates a rate of travel of the floor of 125 feet per hour, and a length of furnace of 15 feet. One man would transfer the hardened plates from the oil to the tempering furnace and another man would receive and sort the plates at the issuing end. The furnace would be hottest at the entering end to accelerate the heating and yet permit of accurate adjustment of final temperature; the correct temperature in the furnace, both the maximum and the final, would be ascertained by trial, and then maintained by pyrometer.

Details of tempering furnace: