THE TOTALLY ENCLOSED FAN COOLED MOTOR AND ITS PRACTICAL APPLICATION IN MODERN INDUSTRY

THESIS FOR THE DEGREE OF E. E.

John Bernard Dakin

1931

THESIS

Electric motors

Title Fan cooled motor

THE TOTALLY ENCLOSED FAN COOLED MOTOR

AND

ITS PRACTICAL APPLICATION IN MODERN INDUSTRY.

Thesis for Degree of E. E.

John Bernard Dakin

1931

THESIS

INTRODUCTION

In preparing this thesis, considerable information, illustrations and data have been secured from various sources. The generous response received from all of the motor manufacturers who were approached while securing this material prompts the author to express his appreciation here for the assistance rendered.

The objective of this study being to determine the extent to which this particular type of motor may be economically applied, without attempting to determine the particular make of motor that might be considered best, the author has purposely refrained from using any manufacturer's name or any material which could be easily identified. It is understood, therefore, that any material embodied herein has been used only for the purpose of illustration or proof and not because of any preference or opinion the author might have for any particular feature of construction.

I. DEVELOPMENT OF THE ALTERNATING CURRENT MOTOR

Since the phenomena called electricity was first discovered, men have been attempting to develop new ways of using it to lighten the burdens of humanity. To attempt to enumerate all of the many ways in which this boon to mankind has been utilised to aid in satisfying the wants of man would be a stupendous task and one which would not add much to the value of this investigation.

In order to prepare the proper background or basis for this particular study, it will be necessary to attempt to trace at least a portion of the developments in one application of this interesting agent or force. In attempting to trace these developments, many confusing reports have been received from different sources. For this reason, any seeming discrepancy in statements made herein will kindly be overlooked since the purpose of this study is not to prove when any particular development took place but rather to determine how one specific form or type may best be applied to modern industry and to what extent it may profitably be used.

The title as previously given, infers that this study concerns the practical application of the totally enclosed fan cooled motor. In order to more clearly state the purpose of this investigation, it may be said that the ultimate objective is to determine not only the practical application of this type of motor, but to ascertain the economical limit to which industrial management may go in investing in this type of equipment since it is an obvious fact that the first cost of this motor is greater than that of the more familiar and popular open motor.

What is now called, in the vernacular of the profession, the open motor, was, of course, the type first developed in the process of applying electricity to the doing of Man's work. Many hours have been spent in studying how to improve it and much money has been spent in experimenting with different ideas or theories which were advanced by those interested in its development.

As the motor reached the stage in its development where it was really practical to use in doing work, other problems were encountered which greatly vexed those who were making use of it. The problems which had been encountered up to this time were either principally mechanical or electrical. One difficulty, however, was encountered which was closely related to both the electrical features and the mechanical elements of the motor. This was the necessity for providing protection for the vulnerable and easily damaged parts of the motor when used in certain places or for certain particular purposes.

There were many different schemes devised for providing protection, most of which were limited in the amount of protection provided. To make the description of these different types as brief and clear as possible, the following definitions have been taken from the National Electrical

Manufacturers Association Publication Number 30-2 issued in October 1930. These definitions, as far as possible, will be given in the order in which they were finally adopted as standards and not as they were first conceived.

1. Open Machine.

An open machine is a machine of either the pedestal bearing or end bracket type, with no restriction to ventilation other than that imposed by good mechanical construction.

2. Semi-Enclosed Machine.

A semi-enclosed machine is a machine in which the ventilating openings in the frame are protected with wire screen, expanded metal, or perforated covers, the openings in which must not exceed $\frac{1}{2}$ sq. in. in area and must be of such shape as not to permit the passage of a rod larger than $\frac{1}{2}$ inch in diameter.

Exception - Where the distance of live parts from the guard is more than 4 in. the openings may be $\frac{3}{4}$ sq. in. in area, but must be of such shape as not to permit the passage of a rod larger than $\frac{3}{4}$ in. in diameter.

3. Totally Enclosed Machine.

An enclosed machine is a machine which is so completely enclosed by integral or auxiliary covers as to practically prevent the circulation of air through its interior. Such a machine is not necessarily air tight.

4. Protected Machine.

A protected machine is a machine in which the armature, field coils and other live parts are protected mechanically from accidental or careless contact, while free ventilation is not materially obstructed.

5. Separately Ventilated Machine.

A separately ventilated machine is a machine adapted for connection with means external to the motor for passing air through it.

6. Enclosed Self-Ventilated Machine.

(a) An enclosed self-ventilated machine is a totally enclosed machine except that openings are provided for the admission and discharge of the cooling air, which is circulated by means integral with the machine. These openings are so arranged that inlet and outlet duct pipes may be connected to them.

(b) When inlet or outlet ducts or pipes or both are used to conduct air to or from an enclosed self-ventilated machine, they shall be so arranged and have ample section to furnish the specified volume of air to the machine.

7. Enclosed Separately Ventilated Machine.

(a) An enclosed separately ventilated machine is a totally enclosed machine, except that openings are provided for the admission and discharge of the cooling air, which is circulated by means external to and not a part of the machine. These openings are so arranged that inlet and outlet duct pipes may be connected to them.

(b) The external fan or blower furnishing air to an enclosed separately ventilated machine, together with the inlet or outlet ducts or pipes shall be of such capacity and so arranged as to furnish the specified volume of air to the machine.

8. Totally Enclosed Fan Cooled Machine.

A totally enclosed fan cooled machine is an enclosed machine equipped for exterior ventilation by means of a fan or fans, integral with the machine but external to the enclosing parts.

As previously stated, it has been found difficult to secure authentic information regarding the sequence of the development of the different types as defined in the foregoing items. Using the information secured and by making a few assumptions (which may not be absolutely correct) the following order of development has been arrived at.

The open motor as defined under Item 1 was of course the starting point. It has advanced far in its development from the crude form in which it was first built and has now reached a stage of efficiency and refinement which no other comparable form or type of prime mover has, due principally to the ease with which it may be adapted to suit varying conditions.

The next step or stage of development seems to have been the "protected" machine. In this type of motor the live parts were protected mechanically, from injury due to accidental causes or careless handling of objects or things which might come in contact with the motor. This was perhaps the first recognition of the fact that outside agencies or conditions could have a very definite effect on the functioning of the motor. At least it leads to the belief that experience had proven that the frame, end bells and bearing supports were insufficient protection for the vital parts of the motor.

The semi-enclosed machine is but another form of definition of the type just mentioned, although the standard description of this specific form seems to have been adopted previous to that of what is called the "protected machine." The use of the semi-enclosure was of course an attempt to secure protection for the live parts of the motor. No definite action seems to have been taken to exclude smaller objects or particles of foreign material from the motor until some time later when the totally enclosed machine was brought out.

This development was the result of experience with motors which had been operating in atmospheres laden with injurious dust, fumes, etc., which seriously affected the performance of the motor and, in many cases, caused the motor to fail entirely. This type of motor, except in the very small sizes, proved to be very expensive to build, principally because of the difficulty encountered in dissipating the heat generated within the motor. This, together with other mechanical and electrical defects, forced the motor manufacturers to devise some more practical means of providing the necessary protection to the motor. Many schemes were devised and tried out with this objective in view, some of which were adopted and standardized by certain manufacturers as evidenced by the descriptions given in Items 5, 6 and 7.

The enclosed self-ventilated machine provided means integral with the motor for circulating the necessary cooling air through the motor but did not prevent this air from coming in contact with the live parts of the machine. This, of course, necessitated securing the cooling air from a source which was not contaminated with injurious matter, particles or fumes. The expense of this type of construction and installation was found to be prohibitive in all but the most extreme cases.

The enclosed separately ventilated motor was but a variation of the enclosed self-ventilated motor in that the cooling air must be brought to the machine from a suitable outside source by some means external to the motor itself. This method was found to be more expensive and more productive of operating troubles than the self-ventilated motor and was therefore used only in the most extreme cases. None of the many schemes devised up to this time were very successful and continued attempts were made to improve the existing methods or to devise new ones.

The next important step or development was the production of the totally-enclosed fan cooled machine, in which the live parts of the motor were entirely enclosed, the cooling air being supplied and circulated by a fan or fans integral with the motor but outside of the enclosure. This type of motor, after much research and experimental work, was finally found to be a solution to the problem from the performance standpoint and much less expensive to build than any of the other types. The motor manufacturers, having arrived at what they considered a practical solution of the vexing difficulties which had been confronting them, then devoted their energies toward improving and refining the construction of the motor. The improvements which have been incorporated in this type of motor in the last four years have been very numerous and important. The discussion of this type of motor which follows is based on motors having the latest improvements and considered to be among the best available.

II. COMPARISON OF TOTALLY ENCLOSED FAN COOLED MOTOR WITH STANDARD OPEN MOTOR

A. Mechanical Construction.

Before the discussion and comparison of the two types of motors is actually started, one important fact should be stated in order that some of the handicaps under which the manufacturers have been laboring in developing the Totally Enclosed Fan Cooled motors may be more clearly understood.

In the past many unsuccessful attempts were made to standardise the principal dimensions of open motors. Due possibly to the lack of proper organisation on the part of those advocating the necessary changes, these attempts were fruitless. Some four years ago another attempt was made to bring about the desired result, which was successful. At the present time each of the motor manufacturers is producing a line of motors which are interchangeable with those of other manufacturers who are members of the National Electrical Manufacturers Association.

Previous to this momentous change, the individual manufacturers had been attempting to make their line of totally enclosed fan cooled motors as nearly interchangeable with their line of open motor. To be consistent then, under the new scheme, they have been endeavoring to manufacture a line of totally enclosed fan cooled motors in the new standardised frame sizes which would be interchangeable with the new line of open motor sizes. In doing so, they have been laboring under space limitations and other serious handicaps which, by one who is familiar with motor construction, will be readily understood.

To simplify this discussion and aid in illustrating the features of construction incorporated in the Totally Enclosed Fan Cooled Motor, the Illustrations numbered 1 to 8 were selected. As previously stated, these illustrations were selected because they best served the purpose and not because of any actual individual superiority.

Referring to Illustration No. 1, the construction shown here is typical of the features embodied in practically all of the different makes of motors on the market today, especially in the smaller sizes. (Frames 224 to 404 incl.) To secure the proper consideration of the important points, it will be best to discuss each part of the motor separately in comparing it with the open motor.

The frame of this motor is inherently the same as that of the open motor, the air duct openings in the center of the frame, however, are closed by means of sheet metal covers. These coverings are added for the sole purpose of directing the blast of cooling air across the entire face of the frame as well as across the stator laminations and the radiating surface of the inner enclosure.

The stator construction is the same as that used in the open motor, the various manufacturers using practically the same methods of stator iron assembly, insulation, coil assembly, etc., as in the open motor. The outer surface of the stator iron is left exposed to the direct action of the cooling air.

At each end of the stator, an enclosing shield has been added which forms part of the enclosure around the live parts of the motor. This enclosing shield, which is as thin as possible in order to offer the least hindrance to the quick transfer of heat and still possess the necessary mechanical strength, is very carefully joined to the stator and machined around the outer edge to form a dust tight joint with the end cover.

The end cover shown in Illustration No. 1 is formed from sheet steel, of sufficient mechanical strength to withstand all normal usage, flanged at the outer edge to fit over the enclosing shield with the inner surface carefully machined. The inner edge of the center opening in this shield forms a stationary seal with the bearing housing and bearing cap, a vellumoid gasket being added for extra measure to insure a tight joint.

The remainder of the enclosure is provided by the cartridge type grease-packed ball bearing. This type of bearing has been chosen by practically all of the manufacturers since it lends itself best to the problem in question, that of enclosing the vital parts. At this point we find the only "running seal" in the whole enclosure. It is, of course, impossible to build a motor with no running seals, since the shaft must extend through the enclosure if the motor is to be used for transmitting power. In this type of construction, the labyrinth seals at B and B' are depended on to exclude all injurious foreign matter which might work in around the shaft. This form of seal has been found to be most efficacious and least liable to be a source of mechanical trouble. It has also been found that if the labyrinths are long enough, this type of seal will successfully act as a flame shield as well.

The type of enclosure just discussed is not used by all manufacturers, some of whom make use of the bearing brackets to form the dust tight enclosure as well as to support the bearings. This form of construction is shown in Illustration No. 2. There are, of course, advantages and disadvantages in both forms of construction, the matter of preference, however, is a matter for the individual to settle since it is not the objective of this study. It can safely be said however, that, all other things being equal, the form of construction which offers the least chance for the entrance of injurious foreign matter, either through poor joints, careless assembling, failure of seals, easily damaged parts or other causes, is the type to be preferred.

Continuing with the discussion of the construction shown in Illustration No. 1, we find that the end brackets of this motor are used primarily to support the bearings and to preserve the aligmment of the rotor in the stator opening. This function is as important in this type of motor as it is in any type because of the necessity of maintaining uniformity in the air gap. On the pulley end of the motor, it also serves to guide the cooling air nearer to the bearing. This is very desirable, since some difficulty has been experienced by some of the manufacturers due to the tendency of this bearing to overheat.

The fan mounted on the rotor shaft at the opposite end from the pulley end is enclosed with a housing which serves a double purpose. It serves to guard the fan from injury as well as those who work with the motor. Its prime purpose, however, is to direct the incoming air. The design of this cover and the fan is such that the incoming air is sufficient in quantity to adequately cool the motor and travels with sufficient velocity through the air passages to prevent, in so far as possible, the depositing of foreign material in the ducts. The design of this fan has been very carefully studied since it requires power to drive it and any added power consumption, of course, tends to lower the efficiency of the motor. The loss incurred by the addition of this fan will be discussed more in detail in connection with the electrical characteristics of the motor.

The rotor of this motor is essentially the same as the rotor of the open motor, the only difference being a slight change in the design of the fans which are integral with it. In the open motor, the function of these rotor fans was to force the air to circulate around the rotor and out through the openings in the end frames and through the stator air ducts. In this motor, the fans serve to circulate the air from the center of the motor, where the heat naturally would be the greatest, to the radiating walls of the enclosure. Since these fans represent no addition to the motor, they therefore represent no added power consumption. The fans in this instance are made of steel, being welded to the stator end ring.

Some of the manufacturers, in the earlier stages of the motor's development, made use of a fan at each end of the motor, leaving off the sheet metal covering over the air ducts through the frame. In this type of construction, the air was drawn in at each end of the motor and passed over the end enclosure and stator iron and out through the frame air ducts at the point marked A. Actual application together with close study of the results obtained have led practically all of the manufacturers to adopt the one fan type of construction as standard. The ultimate objective being to simplify the construction of the motor, provide the correct amount of cooling air, eliminate in so far as possible the deposit of foreign material in the air ducts and to consume as little power as possible in driving the fan.

It has been found that the type of construction shown in Illustrations No. 1 and No. 2 is satisfactory in the smaller frame sizes, and most manufacturers are now showing in their published lists, motors rated up to 40 H.P., 1200 R.P.M. in the same frame size as the correspondingly rated open motor. Some also build motors of larger ratings in the same frame size as the open motor. It is generally recognized, however, that the problem of heat dissipation in the sizes above 40 H.P., 1200 R.P.M. needs special consideration and possibly a different form of construction.

To overcome this obstacle, to complete standardization and interchangeability, some manufacturers have adopted special construction in their cooling devices. One of these types of special construction is shown in Illustrations No. 3 and No. 4. In this form, known as the Mossay Type, are embodied the following features which are designed to provide greater radiating surface for the dissipating of the heat generated within the motor: A steel header ring is welded to each end of the stator ring. Steel tubes extending from one end of the stator to the other are welded into openings in the steel header ring. The rotor has but one fan which is so designed that it causes the air within the enclosure to circulate from the central part of the motor through these steel tubes and back into the enclosure again. The circulation of the inside air through these tubes (which add to the normal radiating surface) causes the heat generated within the enclosure to be carried away faster by the cooling air which passes over the outer surface of the tubes.

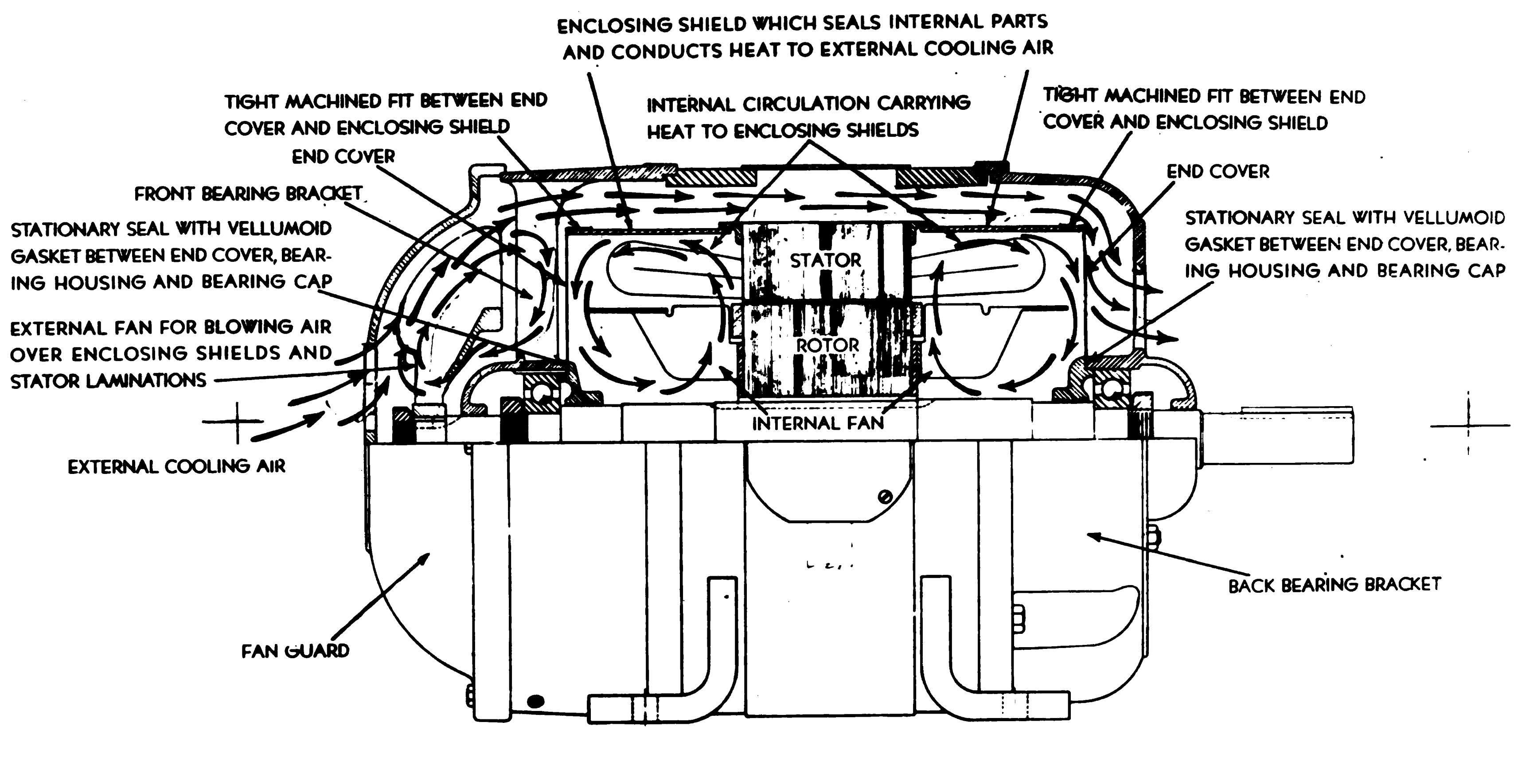
It is interesting to note that the flow of the inner air is counter to the flow of the outer cooling air. Illustration No. 4 shows more clearly the actual appearance of the motor with the tubes incorporated in it. Motors of this or similar types are available in all ratings up to and including 150 H.P. in the National Electrical Manufacturers Association frame sizes.

While it is true that practically all of the manufacturers can furnish totally enclosed fan cooled motors up to 150 H.P. in their old line of frame sizes, they are not interchangeable in all ratings with their own open motor lines and, of course, are not interchangeable with motors built by other manufacturers. It is their ultimate aim, however, to produce a complete line of motors in the National Electrical Manufacturers Association frame sizes which will, of course, be interchangeable with all National Electrical Manufacturers Association motors of the same rating.

Some manufacturers have secured the approval of their complete line of totally enclosed fan cooled motors for use in Class II. installations, defined as follows: Class II. locations are "those in which combustible dust is thrown or likely to be thrown into suspension in the air in sufficient quantities to produce explosive mixtures, or those where it is impractical to prevent such combustible dust from collecting in such quantities on or in motors, lamps, or other electrical devices that they are likely to become overheated because normal radiation is prevented."

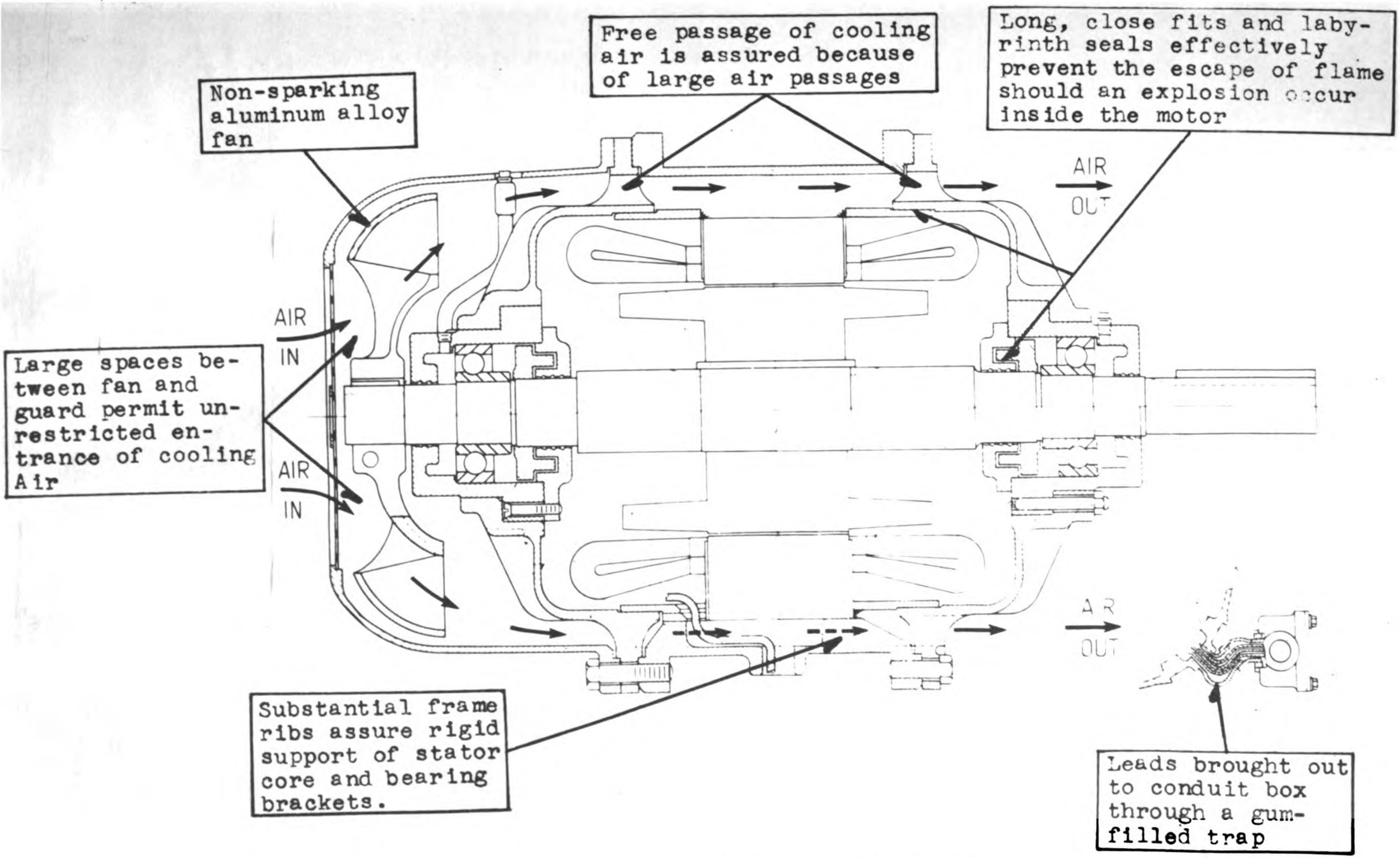
Some of the manufacturers have developed a complete line of what are known as "explosion proof motors," which have been approved for use in Class I. locations. According to the National Electrical Code - Class I. locations are "those in which flammable volatile liquids, highly flammable gases, mixtures or other highly flammable substances are made, used, handled or stored in other than their original containers." In order for a totally enclosed fan cooled motor to be classed as "explosion proof" it must be built to fulfill certain requirements which may be stated as follows: the inner enclosure must be strong enough to withstand any explosive pressures to which it is liable to be subjected. It must also be capable of preventing possible ignition within the motor from extending to surrounding vapors. In case of a burnout in the absence of overload protection, the motor must radiate heat fast enough so that the surrounding gas will not ignite spontaneously.

Some manufacturers have designed a complete line to meet these requirements separate and distinct from their standard totally enclosed fan cooled motor line. Others, by strengthening their enclosures, enlarging the labyrinth seals, using a non-sparking fan and special outlet box, have succeeded in having their standard line of totally enclosed fan cooled motors approved for this class of locations. The prices, of course, are higher than those of the standard line because of the additional features. Comparison of these prices will be made more in detail later.

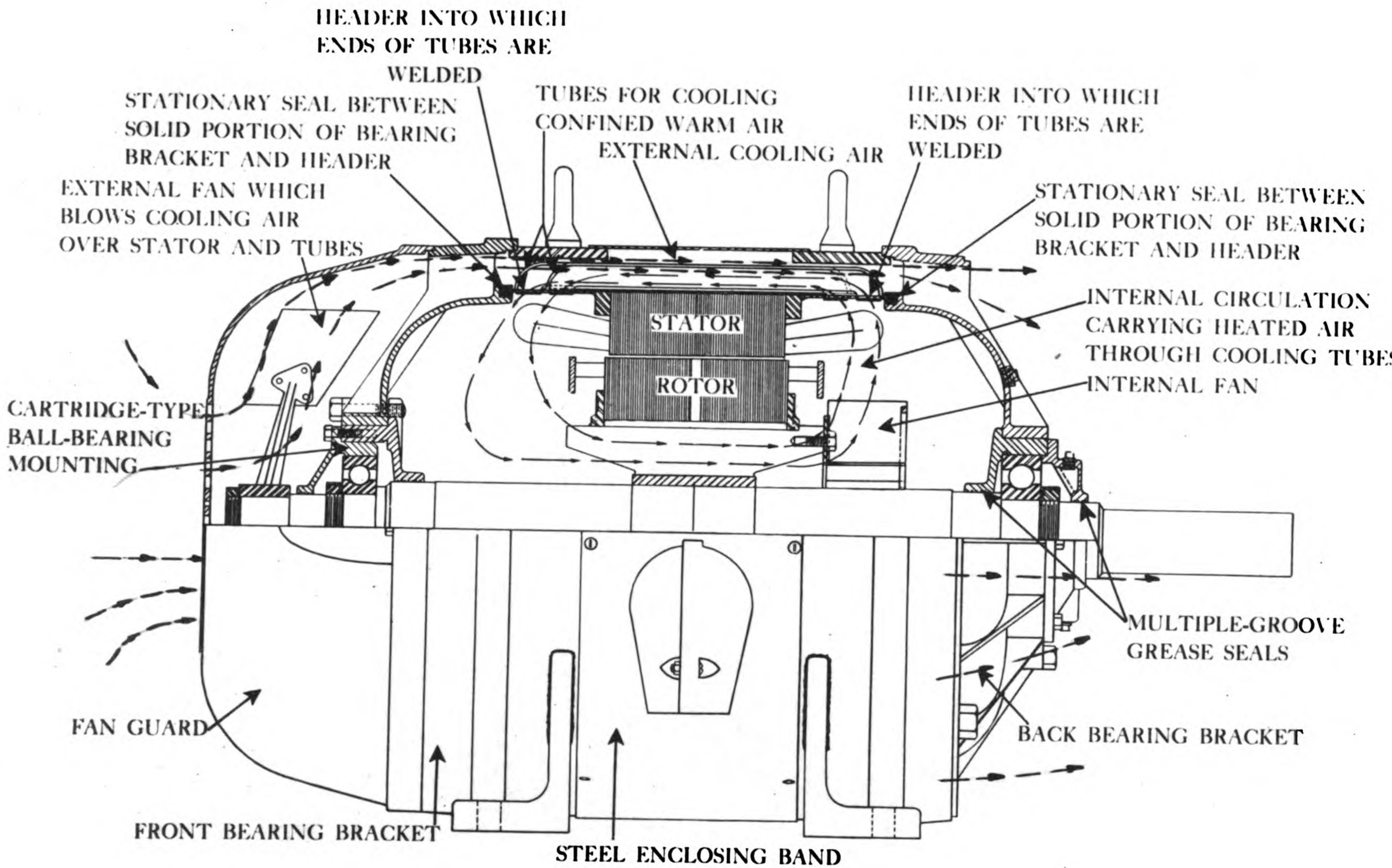

ENCLOSING SHIELD WHICH SEALS INTERNAL PARTS AND CONDUCTS HEAT TO EXTERNAL COOLING AIR
TIGHT MACHINED FIT BETWEEN END COVER AND ENCLOSING SHIELD
END COVER
FRONT BEARING BRACKET
STATIONARY SEAL WITH VELLUMOID GASKET BETWEEN END COVER, BEARING HOUSING AND BEARING CAP
EXTERNAL FAN FOR BLOWING AIR OVER ENCLOSING SHIELDS AND STATOR LAMINATIONS
EXTERNAL COOLING AIR
INTERNAL CIRCULATION CARRYING HEAT TO ENCLOSING SHIELDS
STATOR
ROTOR
INTERNAL FAN
TIGHT MACHINED FIT BETWEEN END COVER AND ENCLOSING SHIELD
END COVER
STATIONARY SEAL WITH VELLUMOID GASKET BETWEEN END COVER, BEARING HOUSING AND BEARING CAP
BACK BEARING BRACKET
FAN GUARD

1426

I



TYPE CS SQUIRREL CAGE MOTOR
FOR USE IN
EXPLOSIVE ATMOSPHERES



Cross-sectional view (Mossay-type) [redacted] Fully-enclosed Fan-cooled Induction Motor.

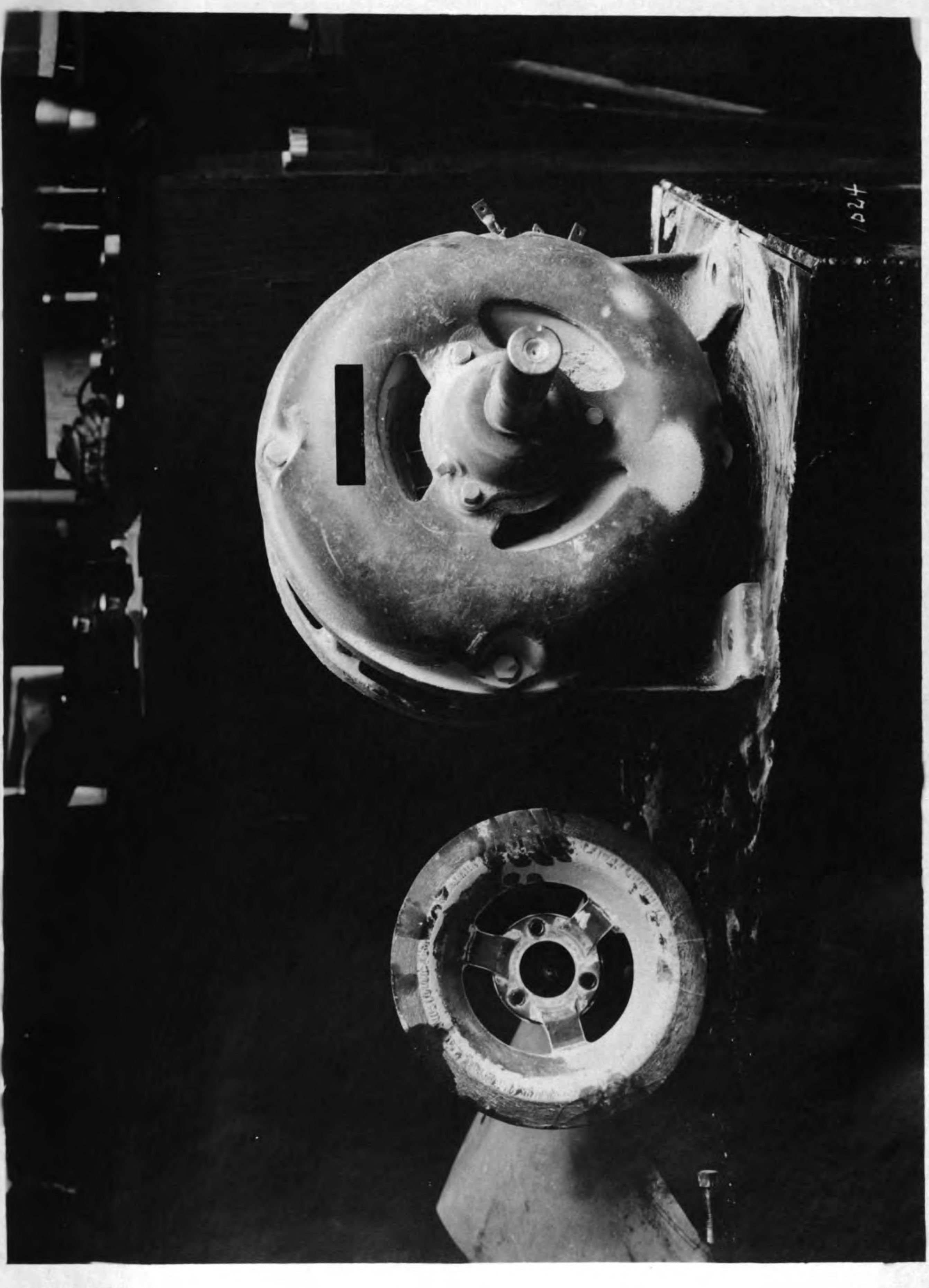
1500

IV

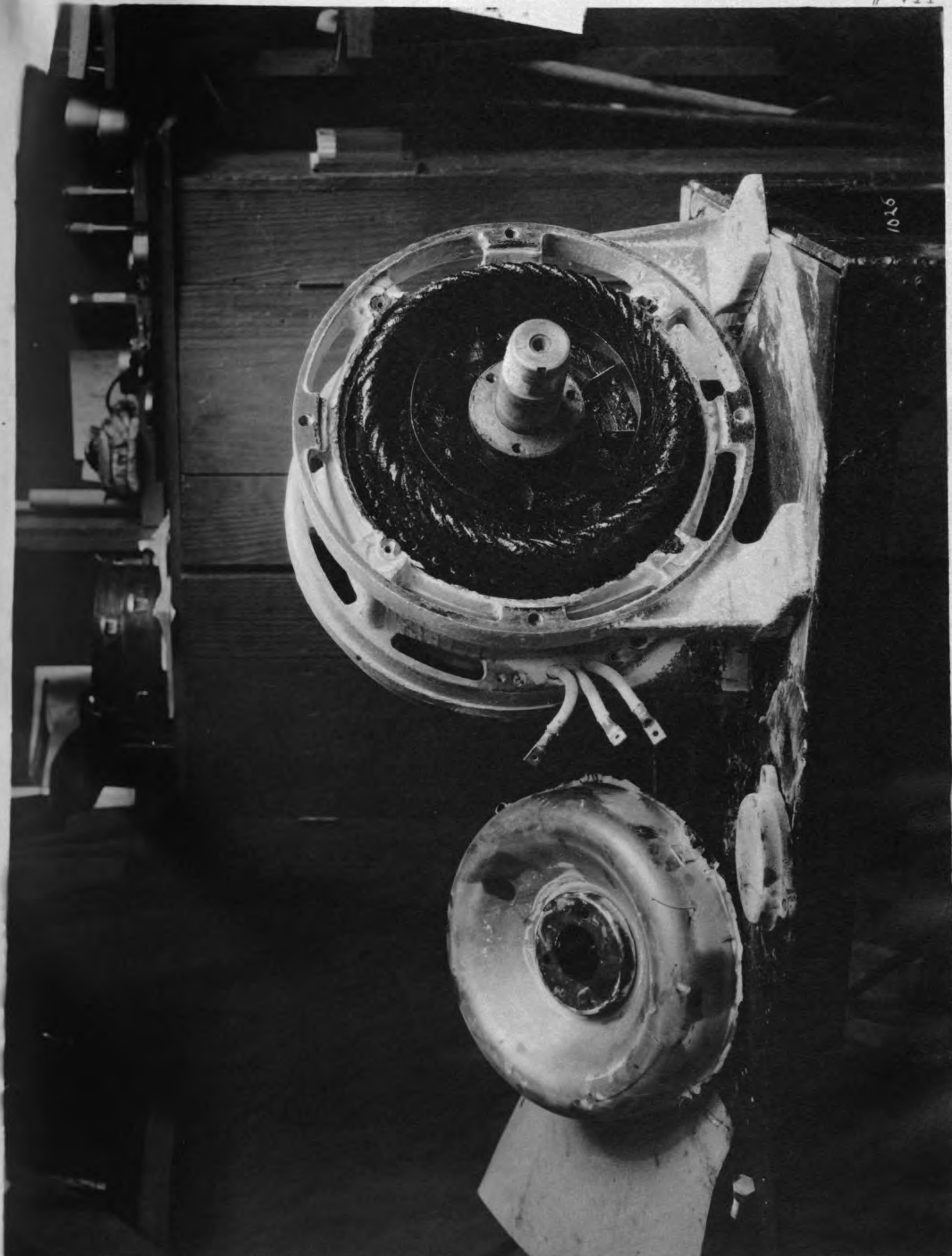
405

V

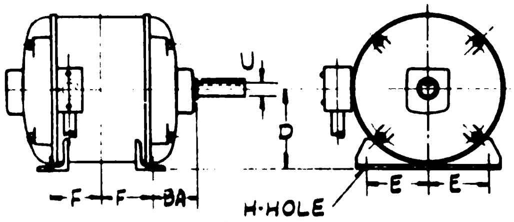
VI



VII



[redacted] ELECTRIC CORPORATION
STANDARDIZED MOTOR MOUNTING DIMENSIONS



ABOVE FIGURE DIAGRAMMATIC ONLY.

SINGLE PHASE, OPEN TYPE
CON'T. 40° LOW VOLTAGE 60 CYCLE
FRAME NUMBERS

H.P.	SYNCHRONOUS R.P.M.								
	3600	1800	1200	900					
1/2				224					
3/4			204	225					
1		204	224	254					
1 1/2	204	224	225	254					
2	224	225	254						
3	224	225							
5	225	254							
7 1/2									

DIMENSIONS IN INCHES

FRAME	J	2E	2F	BA	H	U	KEYWAY	STD. PULLEY
204	5	8	6 1/2	3 1/8	13/32	3/4	3/16 x 3/32	3 x 3 x 3/4
224	5 1/2	9	6 3/4	3 1/2	13/32	1	1/4 x 1/8	4 x 3 1/2 x 1
225	5 1/2	9	7 1/2	3 1/2	13/32	1	1/4 x 1/8	4 x 3 1/2 x 1
254	6 1/4	10	8 1/4	4 1/4	17/32	1 1/8	1/4 x 1/8	4 1/2 x 4 1/2 x 1 1/8
284	7	11	9 1/2	4 3/4	17/32	1 1/4	1/4 x 1/8	5 x 4 1/2 x 1 1/4
324	8	12 1/2	10 1/2	5 1/4	21/32	1 5/8	3/8 x 3/16	6 x 5 1/2 x 1 5/8
326	8	12 1/2	12	5 1/4	21/32	1 5/8	3/8 x 3/16	8 x 6 3/4 x 1 5/8
364	9	14	11 1/4	5 7/8	21/32	1 7/8	1/2 x 1/4	9 x 7 3/4 x 1 7/8
365	9	14	12 1/4	5 7/8	21/32	1 7/8	1/2 x 1/4	9 x 7 3/4 x 1 7/8
404	10	16	12 1/4	6 5/8	13/16	2 1/8	1/2 x 1/4	10 x 7 3/4 x 2 1/8
405	10	16	13 3/4	6 5/8	13/16	2 1/8	1/2 x 1/4	10 x 7 3/4 x 2 1/8
444	11	18	14 1/2	7 1/2	13/16	2 3/8	5/8 x 5/16	11 x 9 3/4 x 2 3/8
445	11	18	16 1/2	7 1/2	13/16	2 3/8	5/8 x 5/16	11 x 9 3/4 x 2 3/8
504	12 1/2	20	16	8 1/2	15/16	2 5/8	5/8 x 5/16	12 x 11 x 2 5/8
505	12 1/2	20	18	8 1/2	15/16	2 7/8	3/4 x 3/8	14 x 13 x 2 7/8

"S" Frames have same dimensions as above except "U" and keyway. The "U" dimension for 444 S, 445 S, 504 S and 505 S frames is 2 1/8" and the keyway is 1/2" x 1/4".

FRAME NUMBERS FOR LOW VOLTAGE, 60 CYCLE, SQUIRREL CAGE MOTORS

OPEN TYPE, CONT. 40°

H.P.	SYNCHRONOUS R.P.M.							
	3600	1800	1200	900	720	600	514	450
1/2				204	224	225	254	254
3/4			204	224	225	254	284	284
1		204	204	225	254	254	284	324
1 1/2	204	224	224	254	254	284	324	326
2	224	225	225	254	284	324	326	365
3	224	225	254	284	324	326	365	404
5	225	254	284	324	326	365	404	405
7 1/2	254	284	324	326	365	404	405	444
10	284	324	326	365	404	405	444	445
15	324	326	365	404	405	444	445	504
20	326	364	404	405	444	445	504	505
25	364-S	365	405	444	445	504	505	
30	365-S	405	444	445	504	505		
40	404-S	444	445	504	505			
50	405-S	445-S	504	505				
60	444-S	504-S	505					
75	445-S	505-S						
100	504-S							
125	505-S							

TOTALLY ENCLOSED, FAN COOLED, CONT. 55°

H.P.	SYNCHRONOUS R.P.M.							
	3600	1800	1200	900	720	600	514	450
1/2					224	225	254	254
3/4				224	225	254	284	284
1				225	254	254	284	324
1 1/2		224	224	254	254	284	324	326
2	224	225	225	254	284	324	326	365
3	224	225	254	284	324	326	365	404
5	225	254	284	324	326	365	404	405
7 1/2	254	284	324	326	365	404	405	444
10	284	324	326	365	404	405	444	445
15	324	326	365	404	405	444	445	504
20		364	404	405	444	445	504	505
25		365	405	444	445	504	505	
30		405	444	445	504	505		
40		444	445	504	505			
50			504	505				
60			505					
75								

Supersedes
MF-2022-C.
Superseded By

MC-14802

B. Electrical Construction and Characteristics.

As previously mentioned, the construction of the rotor of the totally enclosed fan cooled motor is essentially the same as that of the open motor. The various manufacturers employ the same methods in assembling the iron punchings, rotor bars, end rings, and in keying the rotor to the shaft as they do in the open motor. A careful study was made of these different parts and their assembly in order to make certain that the higher operating temperatures of the totally enclosed fan cooled motor would have no serious effects on the performance of this essential part of the motor.

The stator iron in the totally enclosed fan cooled motor is assembled in identically the same manner as that of the open motor. Some manufacturers, have, however, found that in order to absolutely seal the live parts of the motor they were obliged to eliminate the air ducts which were formerly incorporated in their stators. This, in some instances, has resulted in better efficiencies especially in some of the larger sizes of motors due to the increased amount of iron and improved copper distribution. The principles embodied in the construction of the stator winding have not changed materially. A few of the manufacturers seem to hold the view that less insulation of the stator winding is necessary, because those injurious agents or forces which formerly caused so many insulation failures, have been eliminated by the complete enclosure surrounding the live parts of the motor. Most of the manufacturers still use the same insulating materials and in the same quantities as in the open motor. Experience seems to be proving that this is worth while and it is safe to say that very few of the manufacturers will agree to any material reduction of the amount or quality of the insulation used.

Particular attention has been given by most of the manufacturers to the manner in which the leads are brought out from the stator winding to the connection outlet. The openings through which these leads are brought out of the enclosure are usually sealed with a semi-soft, noncracking compound in a manner similar to that shown in Illustration No. 2. Experience with the earlier types of totally enclosed fan cooled motors has shown that unless these leads are well protected where they pass through the stator iron and the air duct, that the abrasive action of the entrained dust will soon cause failure at this point. Having found that the electrical construction of this type of motor has been given sufficient attention to insure proper performance, long life and production cost comparable with that of the open motor, we then must proceed to the important step of comparing their performance characteristics.

Through the courtesy and assistance of one of the prominent motor manufacturers, performance curves have been prepared from actual test data which shows what can be accomplished with the totally enclosed fan cooled motor as compared to the open motor performance.

The data from which these curves were prepared was taken from the test data secured by testing a group of motors in each of the specified ratings. These curves were prepared for each size of motor in the 1200 R.P.M. rating from $1\frac{1}{2}$ H.P. to 30 H.P. No attempt was made to prepare curves for motors larger than 30 H.P. due to the fact that in industry today by far the greater share of the motors in use are included in that range of sizes, and to a certain extent to the lack of available data on motors of larger sizes. It may also be safely said that when the purchase of a motor of this class, in sizes larger than 40 H.P. is being considered, performance curves should be supplied by the manufacturer and given serious consideration by the purchaser. This statement is justified by the investment involved, the amount of power being applied in one unit and the relatively small number of this size of motors in use in comparison to the number of the smaller sizes.

In making up these performance sheets only the Revolutions per Minute or Slip Curves, the Efficiency curves and Power Factor curves were shown. The Ampere and Kilowatt curves were not plotted since they will, of course, vary uniformly with the efficiency. The Revolutions Per Minute or Slip Curve is, of course, identical since there are no radical differences in the design of the two motors which would cause a variation in the slip.

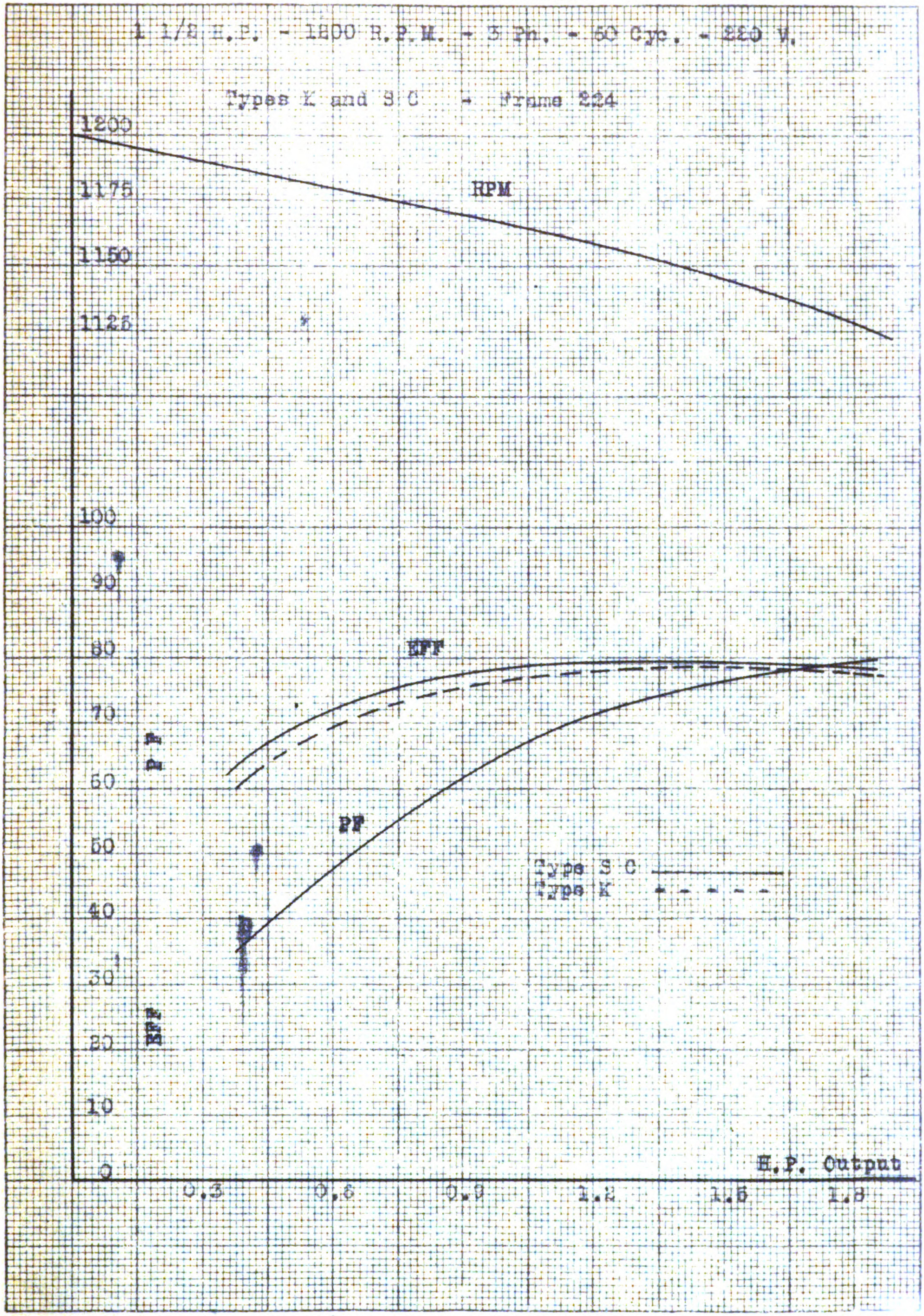
The power factor of the two classes of motors was found to be practically identical. The apparent slight variations encountered were undoubtedly due to variations in the individual motors since the majority were found to be alike. This point is one to which the smaller industries usually fail to give proper consideration. It should be given serious consideration, however, as the larger industries particularly those operating under power rates containing a "power factor" penalty clause, or those having a large power network, have learned by experience that it has a serious effect on their operating costs.

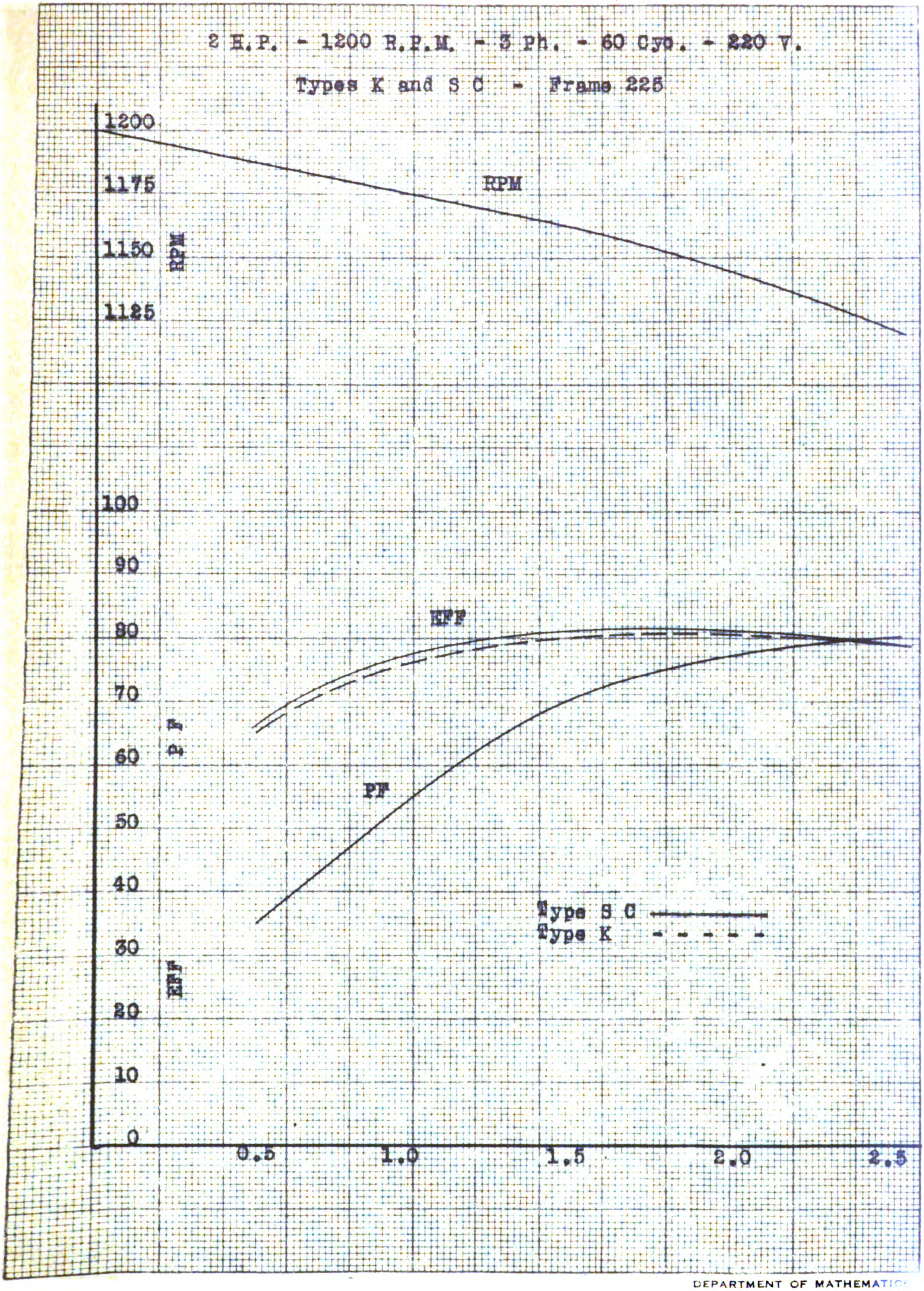
The efficiency curves as shown indicate a lower efficiency for the totally enclosed fan cooled motor, due, principally, to the added load of the cooling fan and the higher operating temperatures. In most of the motors for which the curves were plotted, the efficiency was found to vary from ½ to 2% lower for the totally enclosed fan cooled motor. Inspection of the curves, however, shows that from ¾ to 1¼ full load this variation is from ½ to 1%. Investigation of data secured from some of the manufacturers concerning the losses attributable to the fan show some variation due, without doubt, to the difference in fan design and air duct design. The table given below is for one particular make of motor and does not, of course, apply to all.

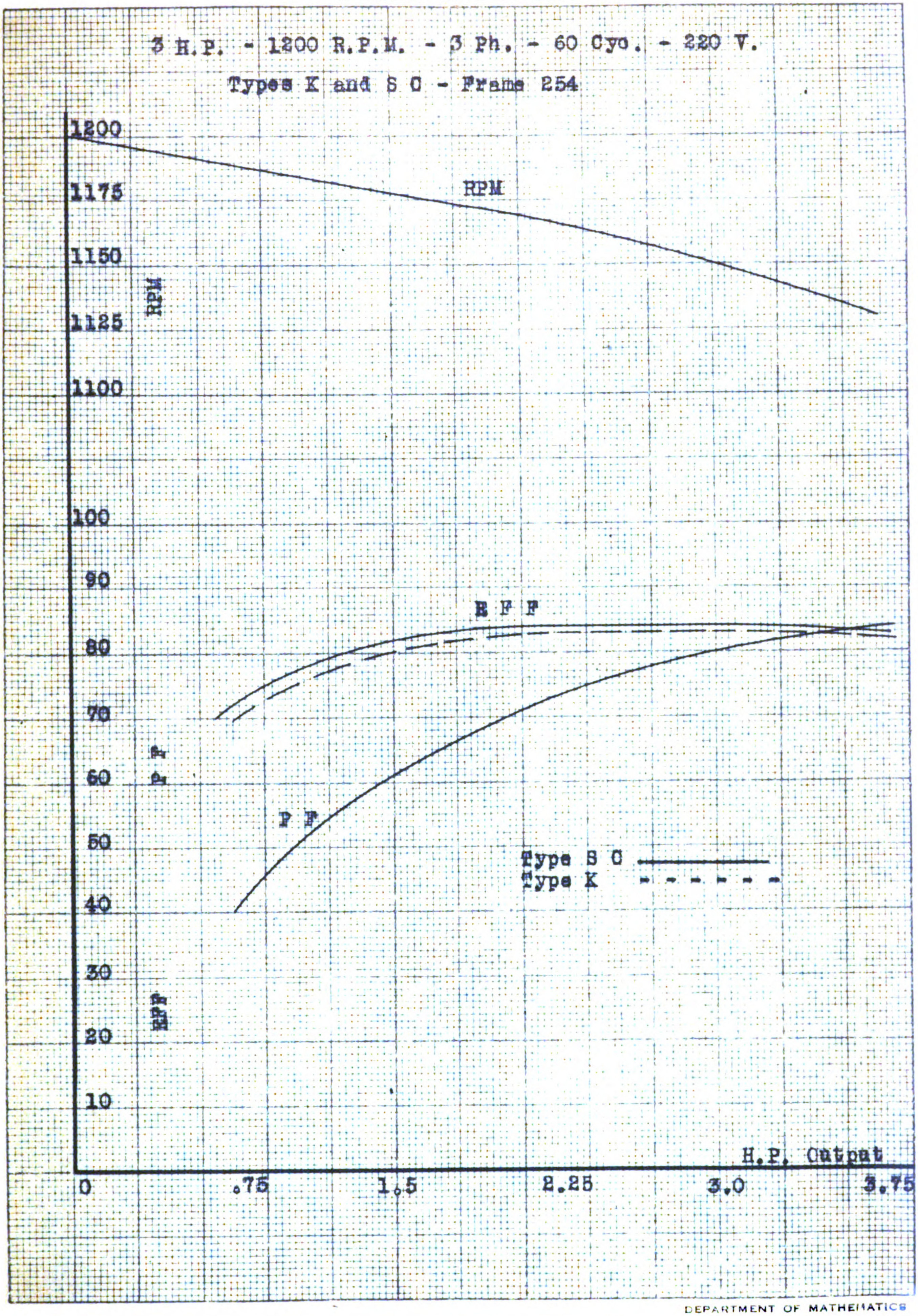
Cooling Fan Losses
in Watts

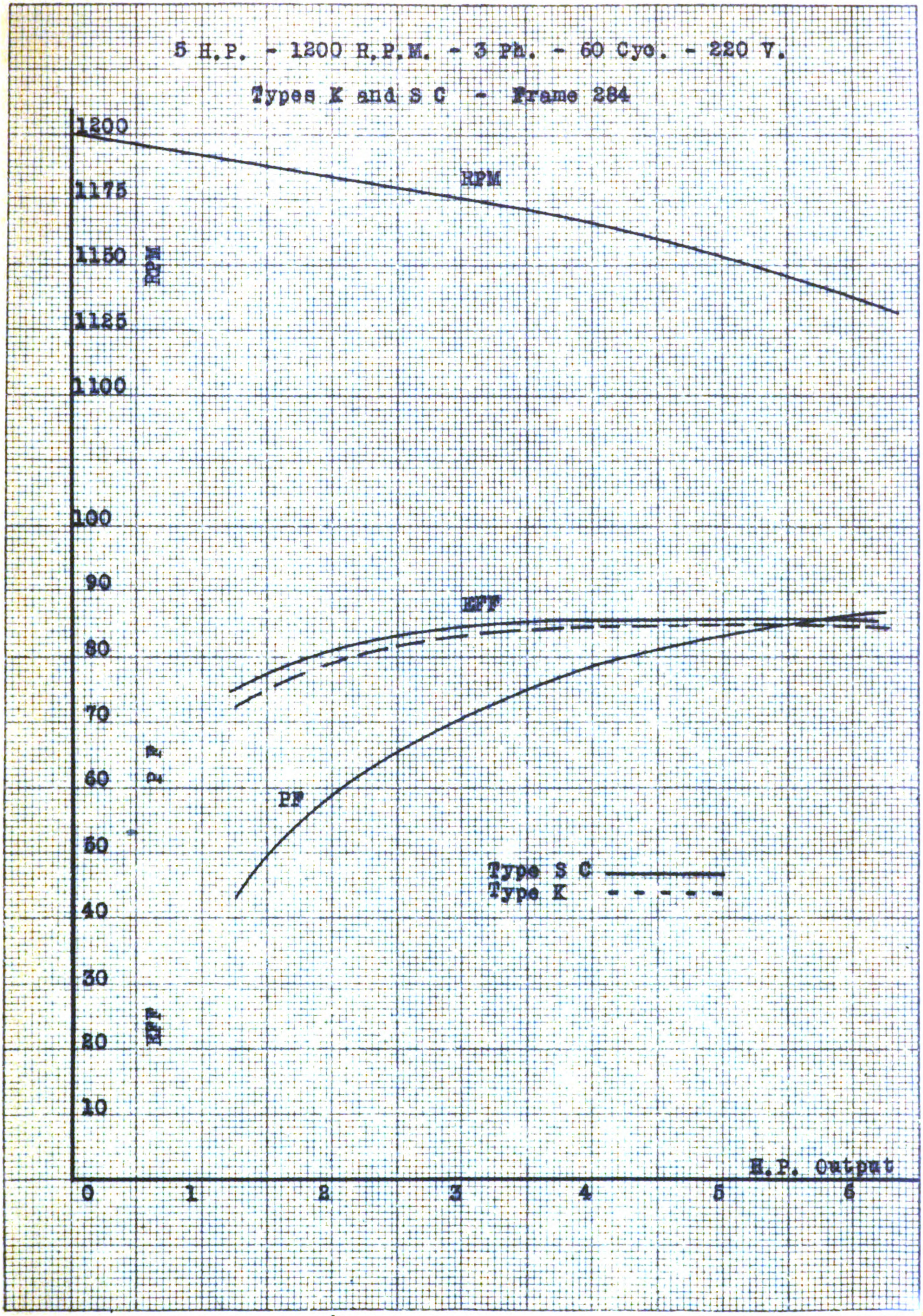
Frame	860 RPM	1140 RPM	1725 RPM
225	8	15	43
254	13	24	67
284	23	42	120
324-6	34	63	180
364-4, 404-5	48	90	255

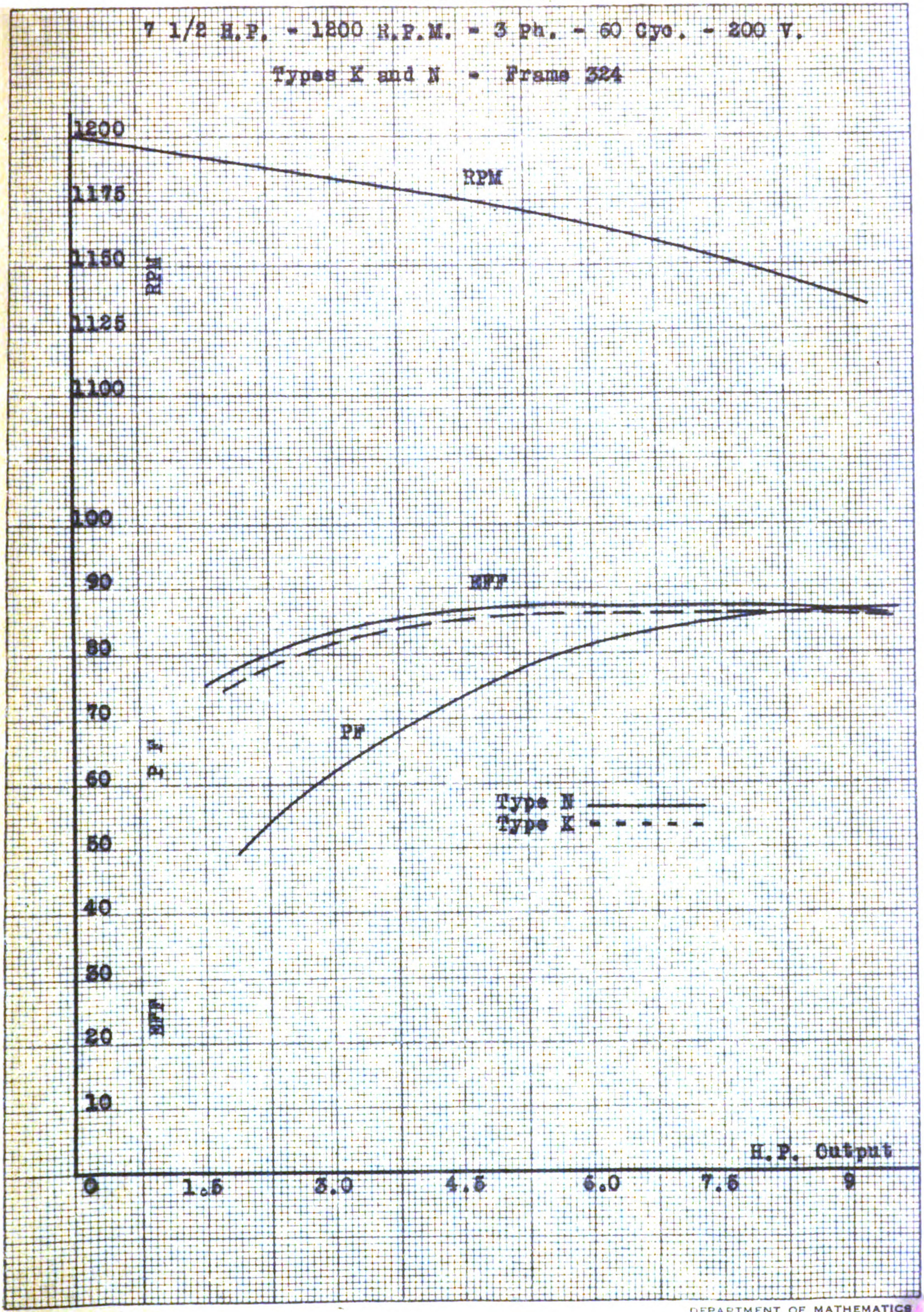
The foregoing points of difference in performance will be given closer scrutiny in one of the following sections of this study.

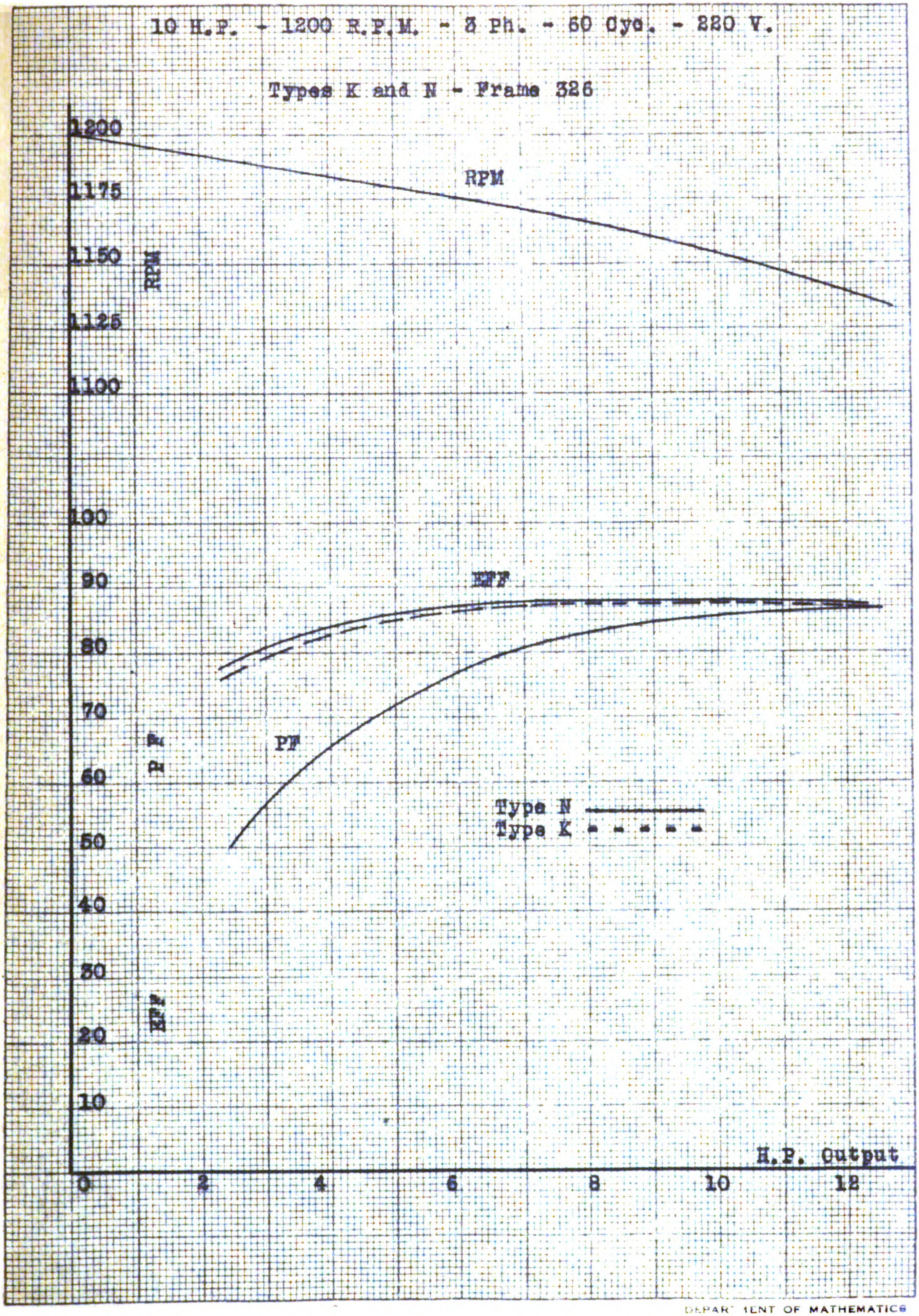

1 1/8 H.P. - 1800 R.P.M. - 3 Ph. - 60 Cyc. - 220 V.
Types K and S C - Frame 224
RPM
EFF
PF
P F
EFF
Type S C
Type K
H.P. Output
1200
1175
1150
1125
100
90
80
70
60
50
40
30
20
10
0
0.3
0.6
0.9
1.2
1.5
1.8

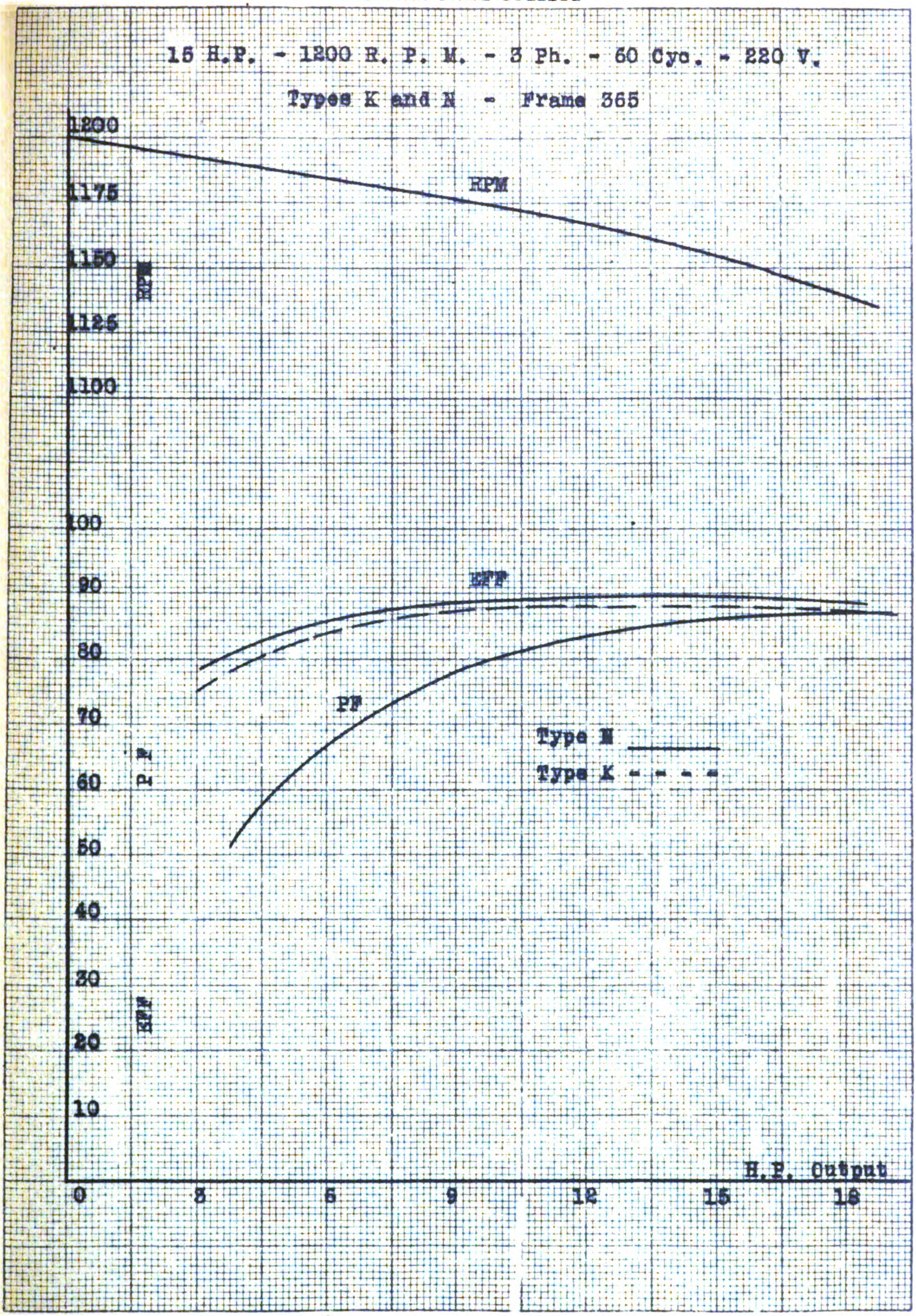

2 H.P. - 1200 R.P.M. - 3 Ph. - 60 Cyc. - 220 V.
Types K and S C - Frame 225
1200
1175
1150
1125
RPM
RPM
100
90
80
70
60
50
40
30
20
10
0
P.F.
EFF
EFF
PF
Type S C
Type K
0.5
1.0
1.5
2.0
2.5


3 H.P. - 1200 R.P.M. - 3 Ph. - 60 Cyc. - 220 V.
Types K and S C - Frame 254
1200
1175
1150
1125
1100
RPM
RPM
100
90
80
70
60
50
40
30
20
10
E F F
P F
Type S C
Type K
H.P. Output
0
.75
1.5
2.25
3.0
3.75


5 H.P. - 1200 R.P.M. - 3 Ph. - 60 Cyc. - 220 V.
Types K and S C - Frame 284
1200
1175
1150
1125
1100
RPM
RPM
100
90
80
70
60
50
40
30
20
10
P.F.
EFF
EFF
PF
Type S C
Type K
0
1
2
3
4
5
6
H.P. Output

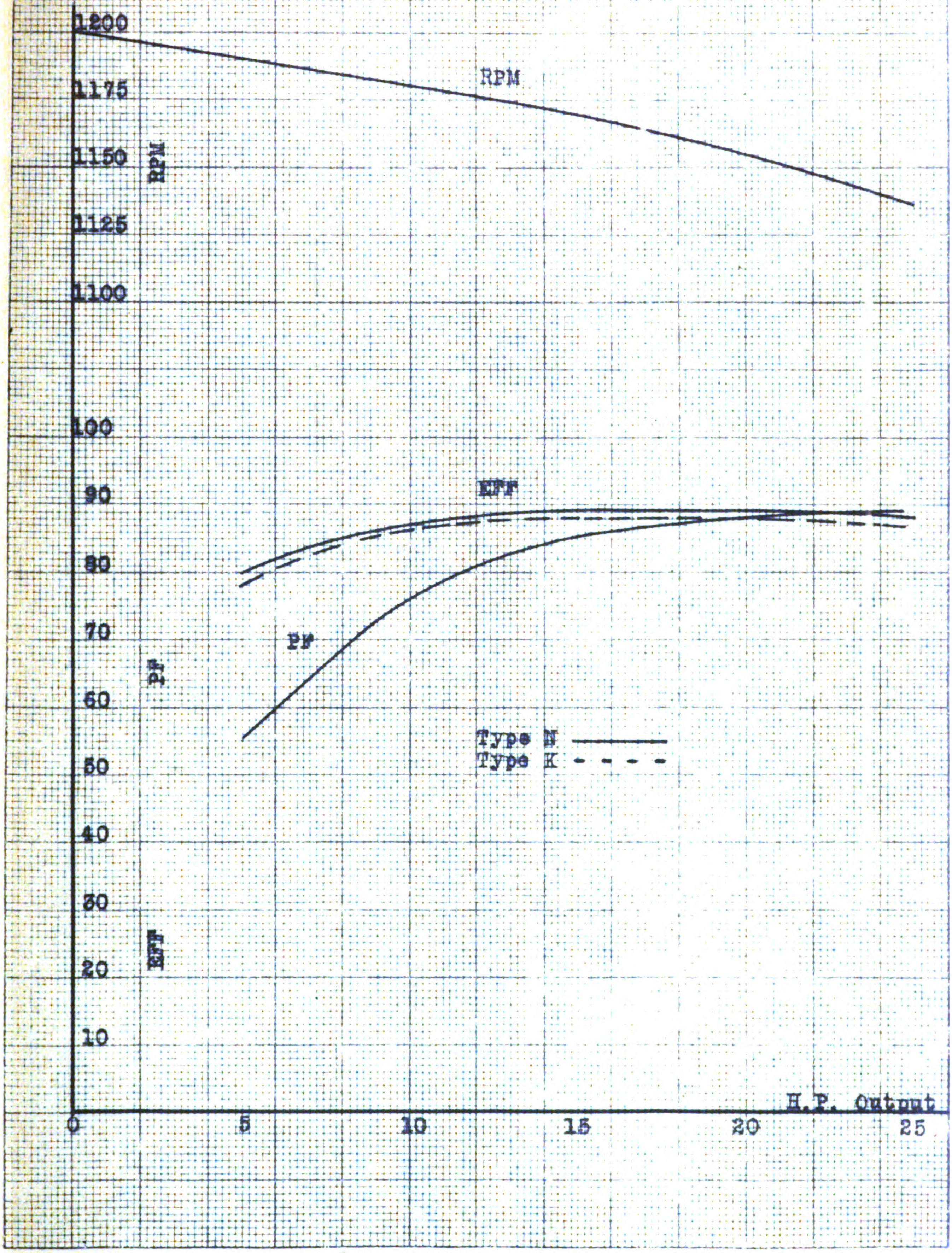

7 1/2 H.P. - 1800 R.P.M. - 3 Ph. - 60 Cyc. - 200 V.
Types K and N - Frame 324
1200
1175
1150
1125
1100
RPM
RPM
100
90
80
70
60
50
40
30
20
10
EFF
PF
P. F.
EFF
Type N
Type K
H. P. Output
0
1.5
3.0
4.5
6.0
7.5
9

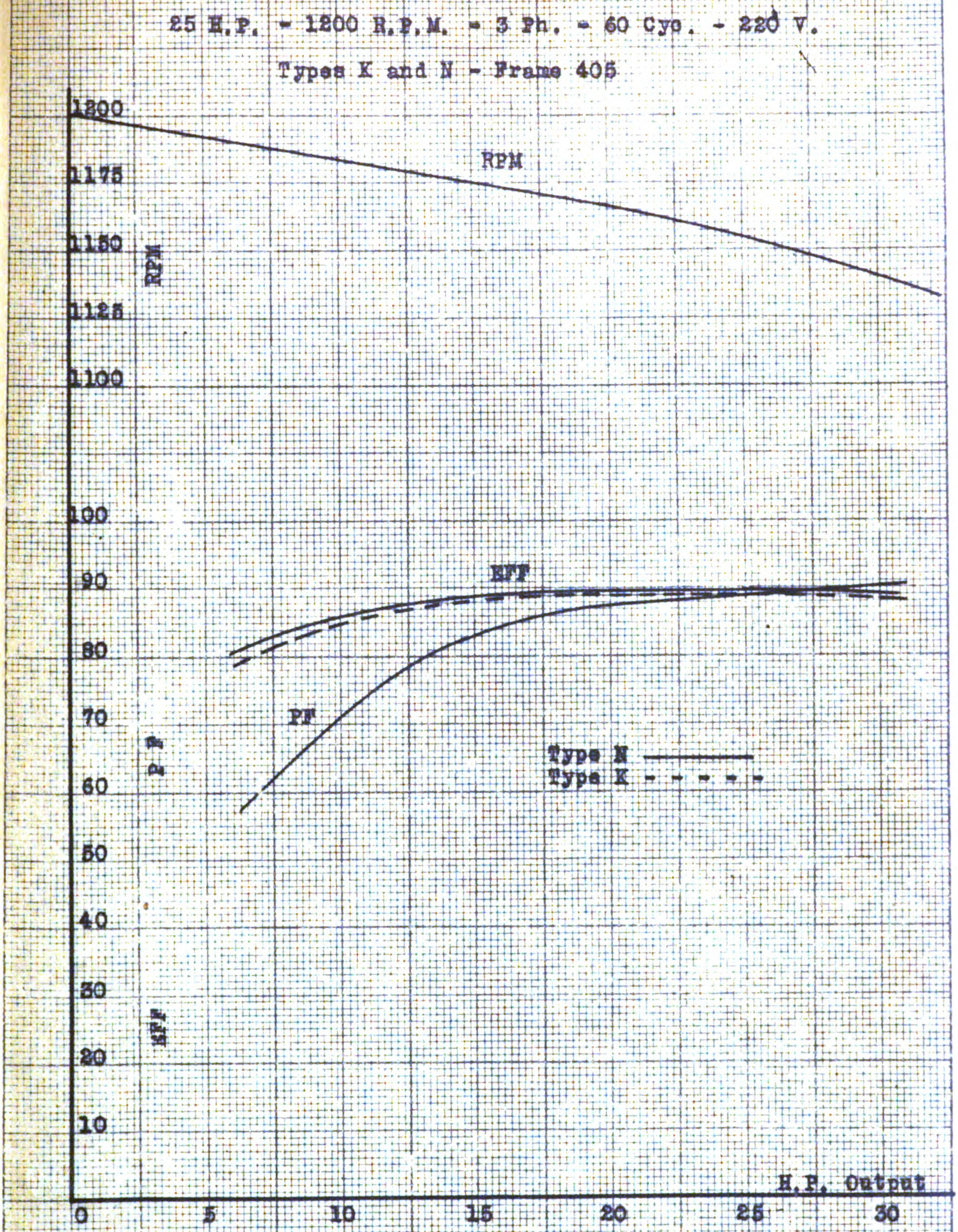

10 H.P. - 1200 R.P.M. - 3 Ph. - 60 Cyc. - 220 V.
Types K and N - Frame 326
1200
1175
1150
1125
1100
RPM
RPM
100
90
80
70
60
50
40
30
20
10
EFF
PF
P F
EFF
Type N
Type K
H.P. Output
0
2
4
6
8
10
12

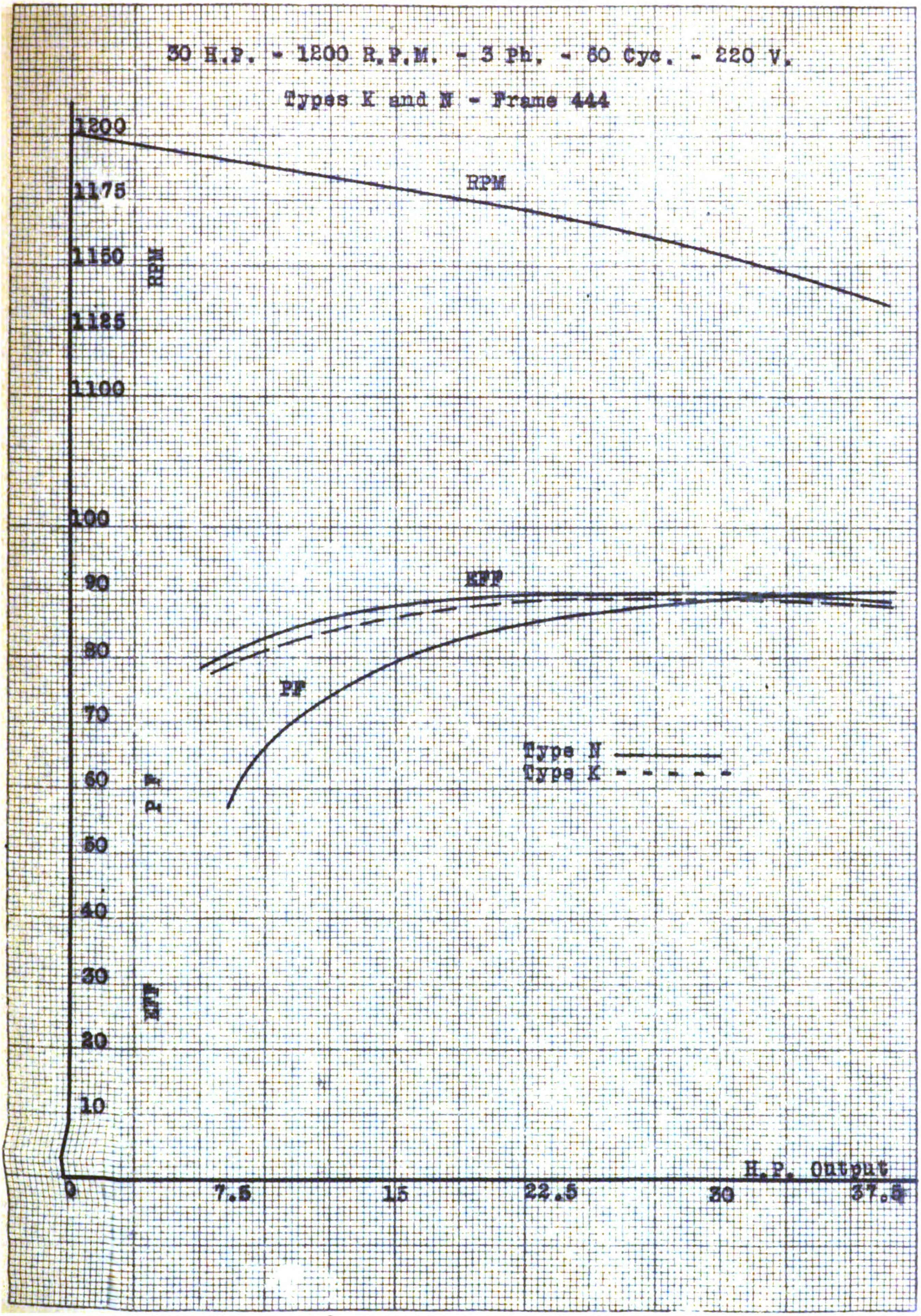

15 H.P. - 1200 R. P. M. - 3 Ph. - 60 Cyc. - 220 V.
Types K and N - Frame 365
1200
1175
1150
1125
1100
RPM
100
90
80
70
60
50
40
30
20
10
EFF
PF
Type N
Type K
P F
EFF
H.P. Output
0
3
6
9
12
15
18

20 H.P. - 1200 R. P. M. - 3 Ph. - 60 Cyc. - 220 V.

Types K and N - Frame 404




25 H.P. - 1200 R.P.M. - 3 Ph. - 60 Cyc. - 220 V.
Types K and N - Frame 405
1200
1175
1150
1125
1100
RPM
RPM
100
90
80
70
60
50
40
30
20
10
EFF
PF
P F
EFF
Type N
Type K
H.P. Output
0
5
10
15
20
25
30


30 H.P. - 1200 R.P.M. - 3 Ph. - 60 Cyc. - 220 V.
Types K and N - Frame 444
1200
1175
1150
1125
1100
RPM
RPM
100
90
80
70
60
50
40
30
20
10
P. F.
EFF
EFF
PF
Type N
Type K
0
7.5
15
22.5
30
37.5
H.P. Output

III. APPLICATION OF TOTALLY ENCLOSED FAN COOLED MOTORS IN MODERN INDUSTRY

The much discussed problem of "Group Drive" versus "Individual Motor Drive" is still a live issue with some industrial engineers. The tendency however, in the majority of cases, seems to be in favor of the "Individual Motor Drive." The arguments pro and con are many and varied and need not be discussed here except to note that with the motor mounted on or near the machine, the motor is in many cases subjected to more of the injurious effects of the dust and dirt, fumes, etc., caused by the operation of the equipment or by nearby machines or processes. This fact has, of course, a decided effect on the recognition given to the necessity of providing protection for the motor.

The most successful maintenance engineers in industry today are those who believe in, and make use of the theory that the best way to handle Maintenance is to prevent it. Briefly, maintenance problems cease to be problems if they are anticipated and prevented. In order, therefore, to keep out of trouble, the maintenance engineer seeks to prevent it.

The totally enclosed fan cooled motor in its present form has proven to be one of the most efficient trouble preventers the maintenance engineer has been able to find. It can be operated in atmospheres laden with dust and dirt so thick that the ordinary open motor would cease to function in less than an hours time if exposed to it, because the dust and dirt are absolutely prevented from coming in contact with the live parts of the motor. It is therefore well suited for application in the metal working industries, foundries, sawmills, glass factories, cement mills, steel mills, grinding and finishing rooms and various other applications.

It is especially applicable in locations where explosive dust is in suspension in the surrounding air. This dust is usually not explosive except when in suspension in the air and requires a spark or flame to ignite it. The motor being built to exclude dust and dirt, rarely fails and if that should happen, the spark or flame would be smothered by the tight enclosure. The motor can therefore be used to good advantage in coal and coke handling plants, sugar mills, fuel pulverisers, flour and feed mills and grain elevators.

Corrosive gases or fumes in the air which passes through an open motor have a serious effect on the insulation of the windings and in some cases attack the shaft, bearings and rotor. The totally enclosed fan cooled motor in reality is not a fume or vapor proof motor, but allows such a small amount of these injurious agents to reach the live parts of the motor that their injurious effect is negligible. It is therefore applicable in most instances in dyeing and cleaning plants, plating and dipping rooms, chemical plants and the paint and lacquer industries.

An open motor operating in the presence of steam, moisture, oil spray, cutting and grinding compounds is usually short-lived because of the injurious effects of these agents on the windings and bearings. The totally enclosed fan cooled motor operating under the same conditions suffers no injurious effects if its design is such that the live parts are really totally enclosed. Many applications of this nature are found in ice plants, dairies, laundries, paper mills, pulp factories, condenseries, building trades, pump installations, power houses, packing houses and canning plants.

While making this study many instances of actual applications were found in which this type of motor had proved very conclusively that it successfully eliminated the disadvantages and handicaps under which the open motor is forced to operate in the classes of locations mentioned above. In some of the instances the totally enclosed fan cooled motor had been operating for more than two years with no attention except for greasing twice yearly. These same motors when opened for inspection were found to be entirely free from dust, dirt, moisture or other injurious matter inside the enclosure.

In one specific instance a 7½ H.P. open motor had been in use, driving a lathe. The material being worked on was cast iron. Due to the excessive amount of fine cast iron dust in suspension in the air and to the amount which actually fell directly upon the motor, it had been exceedingly difficult to keep the motor running. In fact the motor had been rewound at least once in the year preceding the change in spite of constant daily attention. The open motor, when removed, was in such a serious condition that it had been showing signs of overheating for some time. A 5 H.P. totally enclosed fan cooled motor was substituted for the 7½ H.P. open motor and has been in continuous operation for practically two and one-half years with no attention except for what cleaning on the outside which it received when the machine and the surrounding floor was cleared of the accumulation of cuttings and oil drippings. It was greased twice yearly as is the practice with all ballbearing motors. This motor was opened for inspection after 15 months service and again after 11 months service and found to be as clean and free from dust inside the enclosure as it was the day it was installed. The outer air passages, due to proper design, were not clogged or obstructed by the dust and dirt.

In another instance a 25 H.P. totally enclosed fan cooled motor was installed on a large milling machine in place of a 25 H.P. open motor. In the six months preceding the change the open motor had failed twice and had to be rewound due to shorted coils. In this case the motor was mounted above the machine and therefore was not in as exposed a position as the smaller motor just mentioned. This motor has been operating for fully two years with no attention except for greasing.

Numerous instances could be cited of totally enclosed fan cooled motors which have been in continuous service for periods ranging from one to two years during which time they have been subjected to caustic solution spray, cutting oil and compound mixed with metal dust and cuttings, acid fumes, lacquer thinners and solvents. In some of these instances it has been found difficult to find any kind of paint which will stand up for six months time when applied to the buildings and equipment in the localities in which these motors are operating, due to the action of the acid fumes, and caustic solutions employed in the processes.

If time and space permitted volumes could be written concerning actual applications of the totally enclosed fan cooled motor and the results obtained. For those who are, we might say, skeptical, the "proof of the pudding is in the eating," and the surest way to prove to them that what has been said concerning the totally enclosed fan cooled motor and its success is for them to prove it themselves by actually applying the motor on some of their own troublesome applications.

IV. COMPARISON OF COSTS

The ultimate cost to the consumer of any article which he may purchase, whether it be an automobile, a house to live in, a pair of shoes, or as in the case of the question at hand, an electric motor, may be divided into four major parts.

A. Initial cost.
B. Cost of operation.
C. Maintenance costs.
D. Length of service.

The initial cost is the total amount in dollars and cents which the consumer has to pay to purchase the article and place it in service. In the case of an electric motor the installation cost varies with each application as a general thing, and need not be considered in this study except to note that this part of the initial cost will be the same for both types of motors in any specific case. The remainder of the initial cost which we will have to consider is made up only of the actual price paid for the motor. This amount varies according to the discount which the purchaser is allowed. Since this discount varies with the individual customer, it will be disregarded in this study, but of course, should be considered by the individual purchaser when comparing the two types of motors as to ultimate cost.

To more graphically illustrate the difference in initial cost of the two types of motors the accompanying sheet of initial cost data (Page) has been prepared. The figures shown apply to motors rated at 1200 R.P.M. since that rating is the same as that for which the accompanying performance curves were prepared. The figures for the other speed ratings, however, show the same proportionate difference.

As has been previously stated, this study of costs has been confined more specifically to those motors rated at 30 H.P. and lower because the great majority of motor applications is found to be included in this range of sizes and because the amount of initial outlay in the sizes above warrants close scrutiny of each application.

Inspection of the initial cost data sheet indicates, judging by the variation in price difference, that there is neither "rhyme nor reason" involved in the method used by the manufacturer in determining the price of the totally enclosed fan cooled motor. It is true, however, that production difficulties encountered in some of the frame sizes because of space limitations, copper distribution, etc., can be blamed for the apparent erratic variations. The greatest price difference in this group occurs, of course, in the 30 H.P. size being 65.3%. The average difference over the entire group was found to be 52.5%. In the sizes 1.5 to 10 H.P. inclusive, which constitute the greater percentage of installations of motors in the entire group, the average price difference was found to be

41.2%. The average price difference in the sizes 15 H.P. to 30 H.P. inclusive is found to be 52.5%. The average difference over the entire group being 45.7%.

The average price differences shown should serve only as a guide in arriving at a decision as to which type of motor to use when installations of motors in groups, where the sizes will be representative of the group included in this study, are being considered. At first glance the price differences shown would indicate that the totally enclosed fan cooled motor is handicapped to quite an extent by its first cost. Further study of the problem, however, shows that although the price difference seems out of proportion to the additional material and labor needed in producing the totally enclosed fan cooled motor, the additional advantage of lowered maintenance costs, longer life, and elimination of interruptions to service will offset it.

The management of any industry usually sets a definite time limit in which any investment is expected to pay out. This period varies in different organizations and different classes of industry. For the problem at hand, it seems fair to select a three year period since this conforms to the practice of the majority.

By inspection of the cost data sheet we find that the 7½ H.P. and the 30 H.P. sizes show the greatest price difference. It seems logical, therefore, to select two sizes as examples for investigation. Due to the lack of definite records, and the reluctance on the part of many organizations to divulge what records they did have, the author has been forced to rely upon records kept in one organization for actual cost data relative to the study being made.

Two 7½ H.P. motors, one a standard open motor, the other a totally enclosed fan cooled motor, driving the same kind of machines were selected for comparison. The conditions under which these motors were operating were as near identical as could be possible, the following general conditions being found true in each case.

Material being worked on - Dry cast iron.
Average load on motor - 75% of full load.
Hours operation per year - 9 hrs. per day, 200 days - 1800 hours.

The cast iron dust thrown off during the operation was quite fine and much of the finer dust was held in suspension in the air for a short time before it finally settled to the floor. Some of this dust actually settled on the motor and in the case of the open motor clogged the air ducts and windings of the motor to such an extent that it had to be blown out with compressed air at regular intervals. The open motor was found to be running hot and probably was operating at lowered efficiency.

The totally enclosed fan cooled motor was opened once each year for inspection and greased twice yearly. The only cleaning it received was that given it by the operator each day when cleaning up the machine.

The open motor was wiped off, blown out with air, and oiled at regular intervals. At less frequent intervals the oil was drained from the oil wells, the wells were flushed out and refilled with new oil, an average of fifteen minutes daily being spent in performing these operations by the maintenance crew. The motor was also disassembled, cleaned and reassembled four times each year, an average of four bearings being replaced each year due to the abrasive action of the metallic dust which had found its way into the oil. The motor was rewound once because of grounded coils.

By comparing the total of the added initial cost of the totally enclosed fan cooled motor plus the service costs plus the added power consumption due to lower efficiency, with the total cost of maintenance caused by the open motor, we find that the use of a totally enclosed motor in this case would have been a good investment.

7½ H.P. - T.E.F.C. Motor - Eff. @ .75 Full Load - 86%, P.F. - .78

Added initial cost of T.E.F.C. Motor	$ 56.00
Interest on added initial investment (3 yrs.)	16.80
Additional power consumption (3 yrs.) 438 KW Hrs. @ .02	8.76
Cost of greasing and inspection (3 yrs.) 4 Hrs. @ .60	2.40
Total additional cost of the T.E.F.C. Motor	$ 83.96

7½ H.P. - Open Motor - Eff. 87.5% @ .75 Full Load, P.F. - .78

Cost of cleaning, oiling, blowing out with air, etc. 50 Hrs. per year @ .60 Hr. (3 yrs.)	$90.00
12 General overhaul and clean - 4 Hrs. each @ .60 per hour (3 yrs.)	28.80
12 Bearing linings replaced @ $2.90 each (3 yrs.)	34.80
1 Rewind - due to grounded coils (3 yrs.)	50.00
Total cost of maintenance - 3 year period	$ 203.60

By comparison the totally enclosed fan cooled motor in this particular case was found to pay 81 per cent on the added investment instead of the necessary 33 1/3 per cent.

The 30 H.P. motors selected for investigation were found to have been operating under practically the same conditions. The time required for the necessary maintenance, however, was greater because of the size of the motor.

30 H.P. T.E.F.C. Motor - Eff. 89% @ .8 Full Load, P.F. - .87

Added initial cost	$ 175.00
Interest on added initial investment (3 yrs.)	52.50
Additional power consumption (3 yrs.)	24.84
Cost of greasing and inspection (3 yrs.) 5 Hrs. @ .60	3.00
Total additional cost of T.E.F.C. Motor (3 yrs.)	$ 255.34

30 H.P. - Open Motor - Eff. 90% @ .8 Full Load, P.F. - .87

Cost of oiling, wiping, cleaning, 20 Min. per day, 600 days @ .60 per Hr. (3 yrs.)	$ 120.00
12 General overhaul and clean 5 Hrs. each @ .60 per Hr. (3 yrs.)	36.00
6 Bearing linings replaced at $5.40 each (3 yrs.)	32.40
1 Rewind - due to grounded coils and overheating	108.00
Total cost of maintenance (3 year period)	$ 296.40

Again we find that the totally enclosed fan cooled motor is a profitable piece of equipment, the returns on the investment, however, are not as great as in the case of the smaller motor. These cases are indicative of what the totally enclosed fan cooled motor will do under like circumstances. Numerous cases could be cited here where the same type of motor had been as profitable an investment under conditions probably less serious. The fact still remains, however, that conditions vary with each application and those making the decision as to which type of motor to use should study the conditions carefully before deciding. An investment, to be profitable, must produce results and because it does in one case is not infallible proof that it will in others.

Some industrial engineers have, in the past decided that if one totally enclosed fan cooled motor was a paying investment that they should use nothing else irrespective of location or conditions in order to obtain what they term standardisation throughout their entire plant. Experience has taught them, however, that they achieved standardisation and interchangeability to a certain extent but at an exorbitant cost.

There are some points about the cases cited which should be mentioned. Objection might be raised that in the case of the 30 H.P. motor, the item for rewinding the motor might have been avoided by more careful maintenance, in which the totally enclosed fan cooled motor would not have been a paying investment. Experience has shown that, in the plant in which the two motors were located, any motor exposed to similar conditions rarely serves more than two years without developing trouble from broken down insulation with consequent grounded coils if not an actual burnout of the winding. Injurious agents such as fine metallic dust, caustic solutions, cutting oils and compounds, acid fumes and the like, once they reach the windings are almost impossible to entirely remove when the motor is cleaned. The residue is therefore left in the crevices and corners of the windings, in the oil wells and around the leads and, of course, continue to exert their injurious effect on the motor.

In both of the cases cited, no mention was made and no account taken of the possible loss due to interrupted production while the open motor was being serviced. Cases have been found where the interruption to production or service has been productive of losses greater than the cost of a totally enclosed fan cooled motor. To avoid this possibility it has been common practice in many industries to have what are popularly called "Back up" motors in stock in sufficient numbers in the proper ratings to be available for replacement in case a motor fails. This is expensive insurance but has been the only known means of guarding against long and expensive interruptions to service or production.

These points are of greater importance in large plants or establishments than in small plants. The freedom from failures which is characteristic of a totally enclosed fan cooled motor with less necessity for back up motors is one point in favor of those who argue for complete standardization on totally enclosed fan cooled motors. It does not, however, prove the point entirely. It can safely be said that a totally enclosed fan cooled motor is not justified where a standard open motor will operate satisfactorily and economically.

No attempt has been made to discuss in detail the use of the "explosion proof motor" nor to determine to what extent the extra investment as shown on the initial cost sheet can be justified. As the study of the totally enclosed fan cooled motor progressed, it became evident that the applications of explosion proof motors were in most instances special problems and should be considered and studied as such. In reality, whenever the occasion arises in which an explosion proof motor is considered necessary, the risks involved due to the possible loss of life, loss of material, buildings and equipment is so great that the extra investment is a negligible quantity.

INITIAL COST DATA

Based on 1200 R.P.M. Rating

	List Price			Additional Initial Cost for		Additional Initial Cost in Percent of Cost of Standard Open Motor	
H.P.	Open	T.E.F.C.	Ex. Proof	T.E.F.C.	Ex. Proof	T.E.F.C.	Ex. Proof
1½	$53.00	$76.00	$115.00	$23.00	$62.00	43.4%	117%
2	58.00	81.00	118.00	23.00	60.00	39.6%	103.5%
3	70.00	97.00	140.00	27.00	70.00	30.8	100%
5	89.00	125.00	186.00	36.00	97.00	40.4%	111.5%
7½	111.00	167.00	210.00	56.00	99.00	50.5%	90%
10	131.00	187.00	235.00	56.00	104.00	42.7%	80%
15	167.00	246.00	350.00	79.00	183.00	47.3%	110%
20	204.00	310.00	380.00	106.00	176.00	51.9%	86%
25	235.00	342.00	610.00	107.00	375.00	45.5%	159%
30	268.00	443.00	656.00	175.00	388.00	65.3%	145%
40	319.00	501.00	760.00	182.00	341.00	57.0%	107%
50	365.00	628.00	885.00	263.00	520.00	72.0%	142%
60	391.00	760.00	975.00	369.00	584.00	92.0%	150%

V. CONCLUSION

The objective of this thesis, as has been previously stated, was to study the practical application of the totally enclosed fan cooled motor and to determine the economical limit to which industrial management might invest in this type of equipment. The material presented in the foregoing discussions, together with the successful applications of this type of motor which were encountered while making this study leads to the following conclusions.

The totally enclosed fan cooled motor is a practical solution to the problem of providing protection for the live parts of an electric motor from outside injurious agents.

It is economical to use this type of motor in the range of sizes included in the analysis of costs in all localities in which the injurious agents are present in sufficient quantity to necessitate extra maintenance costs. In all sizes above the range included in the cost analysis, special consideration should be given to each individual case.

ROOM USE ONLY