DEPARTMENT OF COMMERCE AND LABOR

CIRCULAR

OF THE

BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 34

THE RELATION OF THE HORSEPOWER TO THE KILOWATT

[1st Edition]
Issued June 1, 1912

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There was, before 1911, no precise definition of the horsepower that was generally accepted and authoritative, and different equivalents of this unit in watts are given by various reference books. It is obviously desirable that the horsepower represent the same rate of work at all places. The value most used in electrical practice has been the round number, 746 watts, and in 1911 the American Institute of Electrical Engineers adopted this as the exact value of the horsepower. Thus defined, it is the rate of work expressed by 550 foot-pounds per second at 50° latitude and sea level, approximately the location of London, where the original experiments were made by James Watt to determine its value. The number of foot-pounds per second in a horsepower accordingly varies with the latitude and altitude. This value, 746 watts, will be used in future publications by this Bureau as the exact equivalent of the "English and American horsepower." The horsepower tables in this Bureau's Tables of Equivalents formerly assumed 550 foot-pounds per second as the correct equivalent at 45° latitude, because of the well-established use of 45° as a standard latitude. This gave the inconvenient relation, 1 horsepower=745.6494 watts.

The "continental horsepower," which is used on the Continent of Europe, is similarly most conveniently defined as 736 watts, equivalent to 75 kilogram-meters per second at latitude 52° 30′, or Berlin.

Modern practice is tending toward the use of the kilowatt instead of the horsepower, and this practice is recommended by this Bureau.

S. W. Stratton,
Director.

Approved:
Benj. S. Cable,
Acting Secretary.

I. INTRODUCTION

The value of the "horsepower" may be expressed either in gravitational or in absolute units of power. Confusion often results when one equivalent is reduced to the other, since the former units depend on the force of gravity, which varies from place to place, and the latter units do not. Thus, the usual gravitational value for the English horsepower, 550 foot-pounds per second, when reduced to watts gives a different number according to the value of the force of gravity employed in the conversion, and hence we find different values in various reference books, of which the following may be cited:

	Watts
Kent's Mechanical Engineers' Pocketbook (1903), page 1031	746
Supplee's Mechanical Engineer's Reference Book (1904), page 801	746
Standard Handbook for Electrical Engineers (1908), page 20, and (1910), page 21	745.6
Foster's Electrical Engineer's Pocketbook (1908):	
Page 3	746
Page 12	745.650
Trautwine's Civil Engineers' Pocketbook (1909), page 244	745.956
American Civil Engineers' Pocketbook (1911):	
Page 1197	746
Page 1313	745.7
Hering's Conversion Tables (1904), page 81	745.650
Third edition of Bureau of Standards' Tables of Equivalents (1906)	745.6494

Such confusion has arisen because there has been no accepted authoritative definition of the horsepower. When the horsepower is taken as a specified number of watts, it represents the same amount of power at all places. But when the horsepower is taken as a specified number of foot-pounds per second, the amount of power represented by it varies for different places. This is evident, since the weight of a "pound," as a unit of force, varies [1] in value as g, the acceleration of gravity, varies. Thus, since g is greater for northern latitudes than for southern, the force represented by a definite number of pounds increases as one goes north. This makes this mode of definition of the horsepower very unsatisfactory. It is similar to a proposal once made to define the meter as the length of the seconds pendulum. No one would now consider seriously a unit of length whose amount varies at different parts of the earth. Similarly, a unit of power the magnitude of which varies from place to place can not be acceptable permanently as a unit. From the standpoint of metrology, the definition of any

[1] Some writers prefer to define a pound weight as the weight of a pound mass at a particular latitude, such as 45° (or some prefer the latitude of Paris). Thus defined, the pound would be no longer a "gravitational" unit in the sense of depending on the force of gravity at any place where measurements are made, but instead would be definitely related to the usual "absolute" units by an absolute constant. While this would make the pound of force a definite quantity, it is nevertheless open to the objection that a pound mass would in general have either more or less than a pound weight depending upon its location. However, investigation and inquiry indicate that the majority of opinion regards the pound as a unit of force as equal to the weight of a pound mass at any place where measurements are made, and consequently it varies as g varies.

unit should be rigorous and free from ambiguity. The necessity for a precise definition exists even now in engineering practice. When extensive research is being made upon steam turbines, when tests are made carefully and results are interpreted minutely, there should be no uncertainty in the units used.

A precise definition is desirable even in the commerce of to-day. Misunderstandings might arise over the acceptance or rejection of an engine under test because of the definition of the unit of power. If the power delivered by the engine is measured by the use of a brake with weights, the number of foot-pounds per second observed would be greater, for example, at New Orleans than at New York, since the force exerted by the weights is different for different latitudes and altitudes. Consequently, if the horsepower is defined as a definite number of foot-pounds per second, the same at all places, it is possible that the engine might be accepted if the test were made at New Orleans and rejected if the test were made at New York. These remarks apply to the case of testing an engine when the force is measured by a dynamometer or an indicator, as well as when measured directly by weights. In either case the spring is calibrated by weights. If the springs were all standardized at the same place, then the variation of the force of gravity would not enter the problem. However, in the making of an accurate test, the spring is often calibrated at the time and place of the test. Consequently, in any case, the variation of the force of gravity with locality must be considered in interpreting the results of a test. The differences here discussed are less than 1 per cent, and greater errors than this would be introduced in any practical case by variation in the lubrication, in the measurement of power, and in the quality of steam. Nevertheless, the mean of a series of tests would be taken as the performance of an engine, and if this figure were just on the margin of tolerance, an uncertain definition of the horsepower might cause misunderstandings. No such confusion is possible if the horsepower is defined in such a way as to represent the same amount of power at all places.

On account of the variation with g, and because the equivalents of the horsepower are not decimal multiples of any of the fundamental units, and further because its definition and value are different on the Continent of Europe from its definition and value in England and America, it has long been felt that the horsepower is an unsuitable unit for many purposes. Modern engineering practice is constantly tending away from the horsepower and toward the watt and kilowatt. Particularly in electrical engineering is this true. In Germany it has been proposed to call the kilowatt "Neupferd" (new horsepower), to make its use appeal more strongly to those who have become firmly attached to the horsepower. A definite action has been taken to eliminate the horsepower entirely as a unit of power in electrical engineering. At the International Electrotechnical Commission in Turin, Italy, in September, 1911, it was decided that in all countries electrical machinery, including motors, would be rated in kilowatts only.

II. HISTORICAL

The term "horsepower" as a measure of the activity of machinery was introduced [2] by Thomas Savery, the inventor of an early type of steam engine. The earliest application of the steam engine was in the pumping of water from mines, work which had formerly been done by horses. Savery, in his Miners' Friend, page 29, in the year 1702, says that an engine which will raise as much water as 2 horses working continuously in a given number of hours will do the work or labor of about 10 horses, since relays of horses must be used to keep the work going continuously; such an engine, then, he called a 10-horsepower engine.

James Watt, who is generally known as the inventor of the modern steam engine, adopted [3] the term "horsepower" as a unit for expressing the power of his steam engines and defined its value in gravitational units, viz, foot-pounds per minute. The magnitude of Watt's horsepower was, however, six or eight times as great as Savery's. The value [4] was derived from experiments made under the direction of Watt and Boulton, his business partner, about the year 1775.

Some heavy horses of Barclay & Perkins's brewery, London, were caused to raise a weight from the bottom of a deep well by pulling horizontally on a rope passing over a pulley. It was found that a horse could raise a weight of 100 pounds while walking at the rate of 2.5 miles per hour. This is equivalent to 22 000 foot-pounds per minute. Watt added 50 per cent to this value, giving 33 000 foot-pounds per minute, or 550 foot-pounds per second. The addition of 50 per cent was an allowance made for friction, so that a purchaser of one of his engines might have no ground for complaint. The figure thus arrived at by Watt is admitted to be in excess of the power of an average horse for continuous work, and is proably at least twice the power of the average horse working six hours per day.

Since the time of Watt, his value has been in general use in England and the United States, and 550 foot-pounds per second is known as the English horsepower. As the use of the steam engine spread from England into other countries, the value of the horsepower was translated into the units of the various countries; that is, since the foot and pound had different values in the different countries, the number of foot-pounds in a horsepower necessarily varied. These values were given to the nearest round number, and hence the equivalence to the English horsepower was only approximate, the value averaging about 1 per cent smaller. Hence arose the discrepancies shown in Table I.

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[2] The Life of James Watt, by J. P. Muirhead (London, 1858), p. 153.
[3] John Robison, Mechanical Philosophy, Vol. II (Edinburgh, 1822).
[4] I. P. Church, Statics and Dynamics (New York, 1886), p. 136.
Encyclopedia Britannica, 4th edition, article on "Steam and steam engines," written by John Robison, with foot notes by James Watt, jr.
T. W. Wright, Elements of Mechanics (New York, 1896), p. 251.

TABLE I

Various Values Adopted For The Horsepower

[Foot-Pounds Given in Terms of the Local Foot and Pound]

	Foot-pounds per second	English horse-power	Kilogram-meters per second	Authority.[5]
England and United States	550.	1.0000	76.041	V
Austria (old)	430.	1.0010	76.119	H
Switzerland	500.	0.9863	75.000	A
Sweden	600.	0.9856	74.943	N
Russia	550.	1.0000	76.041	N
Prussia	480.	0.9906	75.325	H
Saxony	530.	0.9869	75.045	H
Baden	500.	0.9863	75.000	H
Würtemburg	525.	0.9890	75.204	H
Bavaria	460.	0.9888	75.190	K
Modern Germany, Austria, France, Italy, etc		0.9863	75.000	V

[5] V=various. H=Des Ingenieurs Taschenbuch-Hütte II (Berlin, 1902). A=F. Autenhiemer Mechanische Arbeit (Stuttgart, 1871), p. 15. N=J. W. Nystrom Elements of Mechanics (Philadelphia, 1875), p. 63. K=Karmarsch und Heeren's Technisches Wörterbuch VI (1883), p. 637; and Alexander's Weights and Measures (Baltimore, 1850).

After the metric system had come into use in France, Germany, and Austria the values of the horsepower in the various countries were reduced to kilogram-meters per second, with the results shown in the table. The values range from 75 to 76 kilogram-meters per second, averaging only a little more than 75. Hence, this round value, 75, has been adopted generally on the Continent as the value of the horsepower.

The English value, 550 foot-pounds per second, is, however, equivalent to 76.041 kilogram-meters per second, and hence it is that there is a difference of nearly 1.5 per cent between the value generally used in English and American practice and that used in continental practice. Reduced to watts, the English horsepower is generally taken as 746 watts, although the precise equivalent, in watts, of 550 foot-pounds per second depends on the force of gravity, and hence on the latitude and altitude. This is discussed fully below.

It is unfortunate that the value of the horsepower on the Continent of Europe was not taken as 76 kilogram-meters per second instead of 75, in order that it might agree with the English value, as was originally intended. It is perhaps unlikely that a change to 76 could now be made, or that an agreement could be reached by which the continental and the English horsepower would correspond to the same number of watts. It is to some extent customary for continental writers to distinguish the two horsepowers by the words "*English*" and "*metric*." We shall call the latter the "*continental horsepower.*" Thus, German writers speak of the "*Englische Pferdestärke*" and the "*metrische Pferdestärke.*" The term "*Pferdestärke*" is now the preferred name for the horsepower in Germany, the old term "Pferdekraft" being unsuitable because "Kraft" means "force." Similarly, in France, the old term "force-de-cheval" has been given up for "*cheval-vapeur.*" There is another unit of power which has been used in Europe, the "*poncelet,*" or 100 kilogram-meters per second. This unit was named in honor of Jean Victor Poncelet, who introduced the teaching of kinematics at the Sorbonne in 1838. This unit was adopted in France shortly before 1846, according to C. F. Peschel.[6] It was adopted as a unit of power in 1889 by the "Congrés international de mécanique appliquée." Its use is still permitted in the electrical regulations issued by the "Association alsacienne des Propriétaires d'Appareils à Vapeur." It has not, however, been much used in practice.[7] This is probably due in part to the fact that the horsepower had so firm a hold as the unit of power, and in part to the very near equivalence of the *poncelet* to the kilowatt. The *poncelet* is open to the same objection as the horsepower when the latter is rigidly defined as a certain number of foot-pounds or kilogram-meters per second, viz, that the power it represents varies from place to place.

III. EQUIVALENTS OF THE ENGLISH AND AMERICAN HORSEPOWER

It is possible to define the horsepower in such a way that the value determined by James Watt will be continued and yet the unit will represent *the same rate of work at all places.* The convenient and frequently used number of watts, 746, happens to be the equivalent of the rate of work expressed by 550 foot-pounds per second *at 50° latitude and sea level,* nearly the latitude of London, where Watt's original experiments to determine the horsepower were made (50° is more nearly the latitude of Lands End, the southern extremity of England). The number of foot-pounds per second in a horsepower at 45° latitude[8] and sea level is then found to be 550.28. The same rate of work will be expressed by a larger number of foot-pounds per second in lower latitudes and higher altitudes, where the force of gravity is less, and by a smaller number of foot-pounds per second in higher latitudes where the force of gravity is greater. The following table gives the number of foot-pounds per second in a horsepower at various latitudes and altitudes, equivalent to 550 foot-pounds per second at 50° latitude and sea level, or to 746 watts. The value of g has been taken from Smithsonian Physical Tables, page 104 (1910).

[6] Peschel's Elements of Physics, Vol. II, p. 250 (London, 1846).

[7] Olof Linders, Physikalischen Grössen.

[8] On account of the well-established use of 45° as a standard latitude, the horsepower tables in this Bureau's Tables of Equivalents formerly assumed 550 foot-pounds per second as the correct equivalent at 45° latitude, which gave the inconvenient relation, 1 horsepower = 745.6494 watts. Future editions of Bureau publications will use the relation, 1 horsepower = 746 watts.

TABLE II

Value of the English and American Horsepower (746 Watts) in Foot-Pounds per Second at Various Latitudes and Altitudes

Altitude	Latitude				
	0° (equator)	30°	45°	60°	90° (pole)
Sea level	551.75	551.01	550.28	549.55	548.82
5000 feet	551.92	551.18	550.45	549.71	548.98
10000 feet	552.08	551.34	550.61	549.88	549.15

The foregoing table may be put in the following approximate form for ease of remembering:

TABLE III

English and American Horsepower at Various Latitudes

Latitude	Foot-pounds per second
90°, pole	549
50°, London	550
(39°, Washington)	(550.5)
30°, New Orleans	551
0°, equator	552

The value of the English horsepower may also be given in metric units for various latitudes and altitudes, as follows:

TABLE IV

Value of the English and American Horsepower (746 Watts) in Kilogram-Meters per Second at Various Latitudes and Altitudes

Altitude	Latitude				
	0° (equator)	30°	45°	60°	90° (pole)
Sea level	76.283	76.181	76.080	75.978	75.878
1,500 meters (=5,000 feet approximately)	76.306	76.204	76.102	76.001	75.900
3,000 meters (=10,000 feet approximately)	76.328	76.227	76.125	76.024	75.923

By interpolation one can take out of these tables the proper value of the horsepower in gravitation measure (either foot-pounds or kilogram-meters per second) for any latitude and altitude.

IV. EQUIVALENTS OF THE CONTINENTAL HORSEPOWER

The continental horsepower is generally given either as 75 kilogram-meters per second or as 736 watts. These two equivalents are independent definitions and are likely to cause confusion *unless* one of them is assigned to some definite place on the earth's surface. As pointed out in the preceding sections of this circular, the unit, to be definite, should represent *the same rate of work at all* places. The continental horsepower, then, should be taken as 736 watts, which is equivalent to 75 kilogram-meters per second at latitude 52° 30′, or Berlin. The number of kilogram-meters per second expressing this amount of power will be smaller than 75 at more northern latitudes and larger at lower latitudes. The values at various latitudes at sea level are given in Table V:

TABLE V

Continental Horsepower (736 Watts) in Kilogram-Meters per Second

Latitude	0° (equator)	30°	45°	60°	90° (pole)
Kilogram-meters per second	75.256	75.156	75.056	74.956	74.857

V. THE BASIS OF DEFINITION OF THE HORSEPOWER

It is considered desirable that the watt and kilowatt be used as the units of power, whenever possible, for all kinds of scientific, engineering, and other work. It is not unlikely that the unit of horsepower will ultimately go out of use. In the meantime, however, it is desirable that its definition be uniform. This circular has been written to point out that if the horsepower is to represent *the same amount of power at different places*, its relation to the watt must be a constant number, and the number of foot-pounds or kilogram-meters per second which it represents must vary from place to place. Table II and others of this circular show clearly this variation with locality.

It might be feared that some confusion could arise because of the independent definitions of the mechanical watt and the "international" electrical watt. The watt and kilowatt are defined primarily in purely mechanical terms, and not electrically at all. That they have been used mainly in electrotechnical work is merely accidental and is due to the fact that they are metric units and so fit in naturally with the metric units in which all electrical quantities are universally expressed. Any kind of power may properly be measured in kilowatts. For example, in the case of the hydraulic power furnished by a flowing stream, the power is given in kilowatts by multiplying 0.163 into the product of the head in meters by the flow in cubic meters per minute; the power is likewise given in kilowatts by multiplying 0.000188 into the product of the head in feet by the flow in gallons per minute. The watt is defined directly in terms of the fundamental units of mass, length, and time, in the "meter-kilogram-second" system, thus: "*The watt is the power* developed by the action, with a velocity of 1 meter per second, of a force capable of giving to a mass of 1 kilogram in one second a velocity of 1 meter per second." The "international watt," however, is defined in terms of concrete electrical standards, which electrical standards represent practically, as nearly as the limitations of experiment allow, the absolute electrical quantities in terms of their theoretical relations to length, mass, and time. The international watt thus defined is the closest concrete realization of the theoretical absolute or mechanical watt which we have. We can not at the present time say whether the international watt is greater or less than the absolute or mechanical watt, but the difference is known to be very small. Consequently, there is in reality no confusion between the mechanical watt and the international electrical watt.

It is hoped that engineering societies and other interests concerned will recognize the value of the "English and American horsepower" as 746 watts, or, 550 foot-pounds per second *at 50° latitude and sea level* (approximately the latitude of London), employing Table II to obtain the value in foot-pounds per second at other places. It is likewise hoped that the value of the "continental horsepower" will be taken uniformly as 736 watts, or, 75 kilogram-meters per second *at latitude 52° 30′* (the latitude of Berlin), and that the value in kilogram-meters per second at other places will be obtained from such a table as Table V of this circular.

It is probably not generally known that these values were adopted by a committee of the British Association for the Advancement of Science in 1873. This was a committee which recommended the cgs system, and on it were Sir W. Thomson, Carey Foster, Clerk Maxwell, J. D. Everett, and others (B. A. Report 1873, p. 222). The committee in its report said: "One horsepower is about three-fourths of an erg-ten per second. More nearly, it is 7.46 erg-nines per second; and one force-de-cheval is 7.36 erg-nines per second." (One erg-nine = 100 watts.)

The Standards Committee of the American Institute of Electrical Engineers adopted, on May 16, 1911, the following rule, which was inserted in the Standardization Rules of the Institute:

> In view of the fact that a horsepower defined as 550 foot-pounds per second represents a power which varies slightly with the latitude and altitude (from 743.3 to 747.6 watts), and also in view of the fact that different authorities differ as to the precise value of the horsepower in watts, *the Standards Committee has adopted 746 watts as the value of the horsepower.* The number of foot-pounds per second to be taken as 1 horsepower is therefore such a value at any given place as is equivalent to 746 watts; the number varies from 552 to 549 foot-pounds per second, being 550 at 50° latitude (London), and 550.5 at Washington. The Standards Committee, however, recommends that the kilowatt instead of the horsepower be used generally as the unit of power.

The same value, 746 watts, is now used by the Bureau of Standards as the exact equivalent of the English and American horsepower. The Bureau, however, favors the use, whenever possible, of the kilowatt instead of the horsepower.