FLY-WHEEL EXPLOSIONS

An illustrated article written for
"Insurance Engineering"

By WM. H. BOEHM, M. M. E.

Compliments of

The Fidelity and Casualty Company
of New York

S. B. F. W. D. 171, 15M, 2-15 (9419)

The Multiple-Indemnity Fly-Wheel Policy of The Fidelity and Casualty Company of New York

Some Prominent Features

The Multiple-Indemnity Fly-Wheel Policy of The Fidelity and Casualty Company reimburses the assured for loss caused by fly-wheel explosions, including loss on the assured's fly-wheels and other machinery, loss on his buildings and other property, loss on the property of others for which he is liable, and his liability for damages on account of personal injuries or death sustained by employees or by others not employees. The policy pays up to its full limit for each fly-wheel accident that occurs at each plant during the policy term. Thus a fly-wheel owner who has a \$50,000 policy may, without the payment of any additional premium, collect as many times \$50,000 as the number of times that \$50,000 losses occur.

The Multiple-Indemnity Fly-Wheel Policy gives the assured the right to elect after an explosion whether settlement shall first be made for property loss or for personal injuries. Under the terms of the policy The Fidelity and Casualty Company agrees to defend at its own cost all personal injury suits brought against the assured, and to pay the costs of the defense including all court costs taxed against the assured irrespective of, that is, additional to, the limit expressed in the policy.

The Multiple-Indemnity Fly-Wheel Policy makes the personal injury indemnity excess insurance over, instead of contributing insurance with, the personal injury indemnity under the assured's liability policy, if one is carried; thus giving the assured a greater available amount of insurance to apply in the settlement of his property damage, than under any other form of policy.

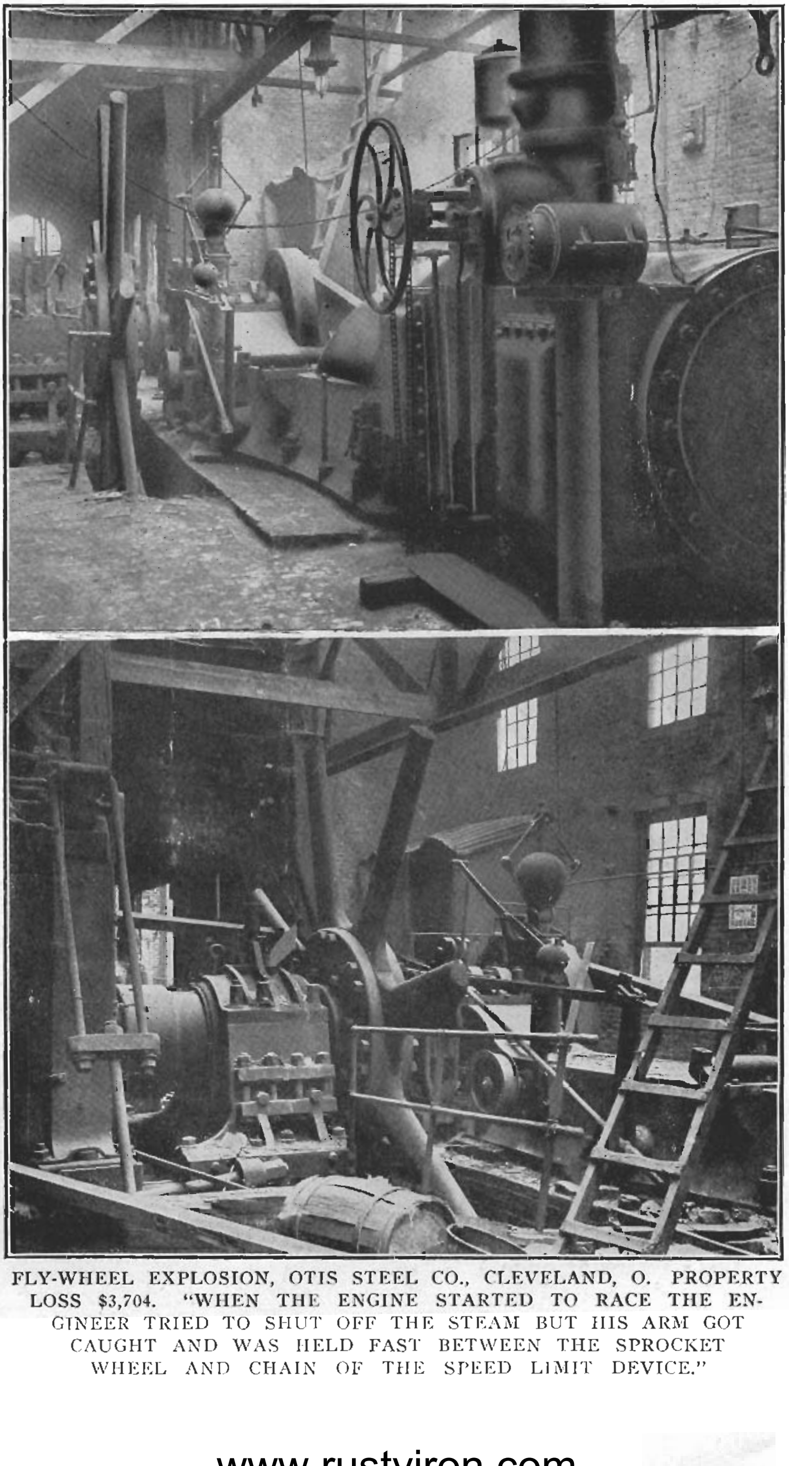
The Multiple-Indemnity Fly-Wheel Policy gives the assured the right to elect, after an explosion, whether any dispute as to the amount of his property loss shall be settled by arbitration, or by other means. Thus the assured is not compelled to determine the amount by arbitration if he has reason to believe that more can be collected by other means.

The Multiple-Indemnity Boiler Policy has no general or sweeping stipulation that "any change material to the risk voids the policy." Other forms of policies usually have such a stipulation, and moreover do not define just what is a change material to the risk.

Inspection Service

The Inspection Service rendered by The Fidelity and Casualty Company under its fly-wheel policies is recognized by eminent engineers everywhere to be the best in the land. The very considerable volume of its steam-boiler and fly-wheel business, the premium income from which amounts to nearly **half a million dollars annually,** warrants it in maintaining an engineering and inspection department of the highest possible standard, and it numbers among its clients representative concerns everywhere.

The Inspectors of the Company are **experts.** Their work is directed by Mechanical Engineers, who are devoting their best energies to this service, and who are recognized authorities on the proper construction and safe operation of boilers and fly-wheels. The Company's advice is much sought and it is freely given without cost to its policyholders.



FLY-WHEEL EXPLOSION, OTIS STEEL CO., CLEVELAND, O. PROPERTY LOSS $3,704. "WHEN THE ENGINE STARTED TO RACE THE ENGINEER TRIED TO SHUT OFF THE STEAM BUT HIS ARM GOT CAUGHT AND WAS HELD FAST BETWEEN THE SPROCKET WHEEL AND CHAIN OF THE SPEED LIMIT DEVICE."

TO OWNERS OF STEAM ENGINES:

This pamphlet is a reprint of a leading article in "Insurance Engineering." It was written by the superintendent of our department of fly-wheel insurance, who was at one time professor of engineering in the State College of South Carolina, and who has made the subject of fly-wheels a special study. The formulæ for determining the stress in fly-wheel rims and the table giving safe speeds for cast iron fly-wheels may, therefore, be accepted with confidence.

When a fly-wheel explodes everything in the path of the flying missiles of cast iron is bombarded as with shot fired from heavy ordnance. The fly-wheel is always a total loss, the engine is usually wrecked beyond repair, other costly machinery is ruined, the building is badly damaged and employees and others are killed or injured.

Such an accident comes in the nature of an overwhelming calamity and may result in a loss of from $5,000 to $100,000, or more, depending upon the size of the fly-wheel and the nature of its immediate surroundings. Accident records show that the percentage of fly-wheels in use that disrupt is greater than the percentage of boilers in use that explode. Insurance statistics show that the percentage of fly-wheel premiums paid out for fly-wheel losses is greater than the percentage of boiler premiums paid out for boiler losses.

Engine owners will, therefore, welcome the protection afforded by our Fly-wheel Policy. It provides an *inspection service* to prevent accident and an *indemnity* to reimburse the assured for all loss in case of accident, including damage to fly-wheels, engines, and other machinery, damage to buildings and other property, and damages for the infliction of personal injury or death.

A postal card addressed to the company direct, or to any one of its branch offices, a list of which is given on the third page of the cover, will receive prompt and courteous attention. If you are not already carrying a fly-wheel policy, we beg to suggest that you will consult your own interests by communicating with us at once.

THE FIDELITY AND CASUALTY COMPANY OF NEW YORK.

Fly-Wheel Explosions

*By WILLIAM H. BOEHM, Member Am. Soc. M. E.**

FREQUENCY OF THESE DISASTERS—CAUSES OF FLY-WHEEL EXPLOSIONS—HOW THE STRESS IN FLY-WHEEL RIMS, DUE TO CENTRIFUGAL FORCE IS DETERMINED—FLY-WHEEL AND BOILER EXPLOSIONS COMPARED—THE TEMPTATION TO RUN AT DANGEROUSLY HIGH SPEED—HOW TO DETERMINE THE SPEED AT WHICH EXPLOSION WILL OCCUR—FORMULÆ AND TABLE GIVING SAFE SPEEDS FOR CAST IRON, WOOD, AND STEEL FLY-WHEELS.

WHEN a heavy train thunders past at high speed, the bystander cannot but be impressed with the immense amount of power that is being exerted. The dark clouds of smoke, the sharp puffs of exhaust steam, the trembling and panting of the almost living giant of steel and iron, the noise of the moving train and the cloud of dust left behind, all convey an impression of tremendous power. If the bystander does not experience an intuitive feeling of danger it is only because of his familiarity with the spectacle.

A stationary engine driving the machinery in an industrial establishment may be putting as much power as this into its fly-wheel, but the bystander sees no smoke, hears no noise of exhaust steam, and the wheel revolves so smoothly and quietly that it conveys to him almost no idea of the power exerted. If the power happens to be transmitted by belting, the high rim speed of the wheel is apparent in the express-train speed of the belt. (It is current practice to operate all fly-wheels at a rim speed approximating a mile a

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*Superintendent Department of Steam Boiler and Fly-wheel Insurance, Fidelity & Casualty Company of New York.

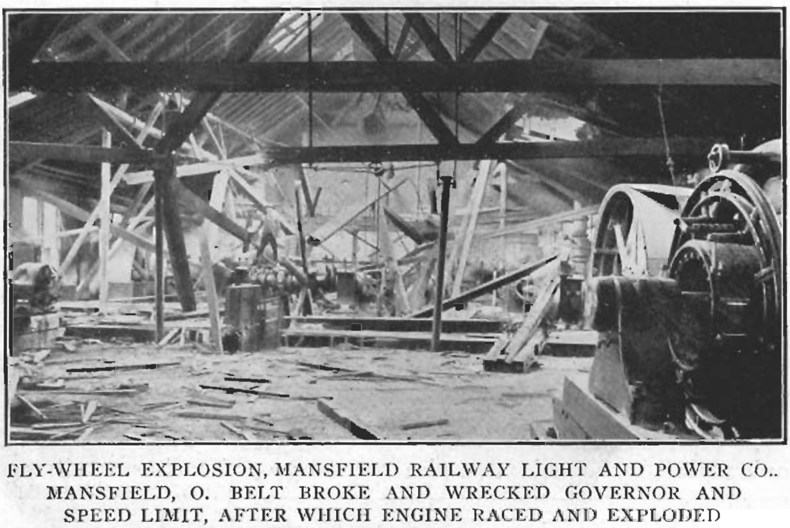
minute). The rim speed, however, conveys only a faint idea of the power developed or of the danger involved.

Whether or not this power and its accompanying danger is perceptible to a bystander, the engineer in charge of the power plant has a grim appreciation of its presence. He has a comprehensive idea of the amount of energy represented in the several boilers that supply steam to the engine, and he knows that the fly-wheel in transmitting this power contains the energy represented in all of the boilers used to run the engine. When he considers the amount of energy thus stored up in the fly-wheel and the awful havoc that would be wrought should this energy suddenly be liberated through an explosion of the wheel, it is little wonder that he has an intuitive feeling of danger. There is cause for it.

FREQUENCY OF FLY-WHEEL DISASTERS.

The writer noticed during one year no fewer than sixty newspaper accounts of serious fly-wheel explosions. Of these, eighteen occurred during two months.

As comparatively few accidents of this kind are reported in the daily press and only a part of the published reports have



FLY-WHEEL EXPLOSION, MANSFIELD RAILWAY LIGHT AND POWER CO., MANSFIELD, O. BELT BROKE AND WRECKED GOVERNOR AND SPEED LIMIT, AFTER WHICH ENGINE RACED AND EXPLODED WHEEL BY CENTRIFUGAL FORCE. ONE PERSON INJURED; PROPERTY LOSS $9,000; WHEEL INSURED.

come under the writer's observation, it is safe to say that fly-wheel disruptions are occurring at the rate of at least twelve a month.

From the nature of the conditions involved, these explosions occur with great violence. Cast iron being a comparatively brittle material, any breakage of a wheel is almost certain to be accompanied by complete disruption. And since disruption nearly always takes place at a rim speed of 3 to 3½ miles per minute, the heavy fragments are hurled with a speed so terrific that everything in their path is mowed down as by a bombardment from heavy ordnance. A single accident often involves the death and injury of scores of employees and a property loss of thousands of dollars.

As an example in point, an accident may be cited that occurred at the Cambria Steel Co., Johnstown, Pa. In that instance the breaking of a governor-belt allowed an engine to run away and burst its 30-foot fly-wheel by centrifugal force. The flying missiles of heavy cast iron wrecked the building and flooded it with scalding steam and water from broken pipes. One man was instantly killed, three more fatally injured, and five others seriously hurt. The building was set on fire.

Another illustration is the accident that occurred at the National Tube Works, McKeesport, Pa. In that instance the

FLY-WHEEL EXPLOSION, MARYLAND RAIL MILLS, CUMBERLAND, MD. ENGINE RACED, ROOF PRECIPITATED ON WORKMEN; 2 KILLED; 10 INJURED.

bursting of a heavy fly-wheel killed one man outright, seriously injured three others, and caused damages estimated by the McKeesport *Times* at $100,000. This estimate included the indirect loss of wages and mill output resulting from the shut down, as well as the direct loss due to damaged machinery and building.*†

It will be seen that the frequency and disastrous results of these accidents is alarming, and that insuring against loss due to fly-wheel explosions is much the same as insuring against loss due to boiler explosions.

TEMPTATION TO RUN AT DANGEROUSLY HIGH SPEED.

Engine fly-wheels may be divided into two general classes, those that serve as a fly-wheel only and those that serve as a combined fly-wheel and belt wheel. As a fly-wheel, the combined wheel serves to prevent sudden fluctuations of speed due to variations in the load on the engine, and to variations in the crank effort. As a belt wheel, it serves to transmit the power developed by the engine.

*Since this was written the National Tube Works have suffered another fly-wheel explosion in which four men were instantly killed and property damaged to the extent of $50,000.

†Since the preceding foot note was written a third fly-wheel explosion occurred at the National Tube Works. In this accident the property loss was $25,000.

FLY-WHEEL EXPLOSION UNION BREWING CO., ST. LOUIS, MO., 40,000-POUND WHEEL ON ICE MACHINE RUNNING NORMALLY AT ONLY 50 R.P.M. MACHINE RACED AND BURST WHEEL BY CENTRIFUGAL FORCE, HURLING 8,000-POUND CHUNKS GREAT DISTANCES. RIM SECTION WAS 13″x16″, TO BREAK WHICH REQUIRED 4,000,000 POUNDS. LOSS $13,423. WHEEL INSURED.

High speed is greatly desired for both of these purposes. High speed means that narrow belts may be used, because the capacity of a belt to transmit power is proportional to its width and to its speed. If the speed of a belt be doubled, for example, it need be only half as wide to transmit the same amount of power. High speed also means lighter wheels, because a narrower-faced wheel will serve to carry the narrower belt required.

In the case of an overloaded engine, more power may be obtained by increasing the speed, because the power developed by an engine increases directly with its speed. If the speed be doubled, for example, the power will be doubled. and this without any increase in the steam pressure. If the engine and wheel will stand the increase in speed, this will give also the advantage of better speed regulation.

The capacity of a fly-wheel to prevent sudden fluctuations of speed is proportional to the weight of the wheel and to the square of its speed. If the speed can be doubled, for example, only one-fourth the weight will be required to give equally efficient speed regulation.

It will be understood from the foregoing that even a slight increase in speed means a considerable saving in the weight and cost of the wheel and in the cost of the belting; and

FLY-WHEEL EXPLOSION HELDERBERG CEMENT CO, HOWES CAVE, N. Y. KEY DROPPED OUT OF GOVERNOR BEVEL GEAR, CAUSING ENGINE TO RACE. THREE WHEELS ALL ON ONE ENGINE BURST; BUILDING DAMAGED.

in the case of an overloaded engine, it may mean saving the cost of a larger engine to develop the power required. The temptation to run fly-wheels at high speed is therefore great, so great in fact that they are often run at a speed dangerously near the limit of safety.

CAUSES OF FLY-WHEEL ACCIDENTS.

Wheels that serve only as fly-wheels have narrow, thick rims, often of approximately square cross-section. Those that serve as combined fly-wheel and belt wheel have thin rims, wide enough to carry the belt used to transmit the power developed by the engine.

Such wheels may fail primarily from two causes, namely, from overload or from overspeed.

Overload may be produced in a number of ways, among which may be enumerated:

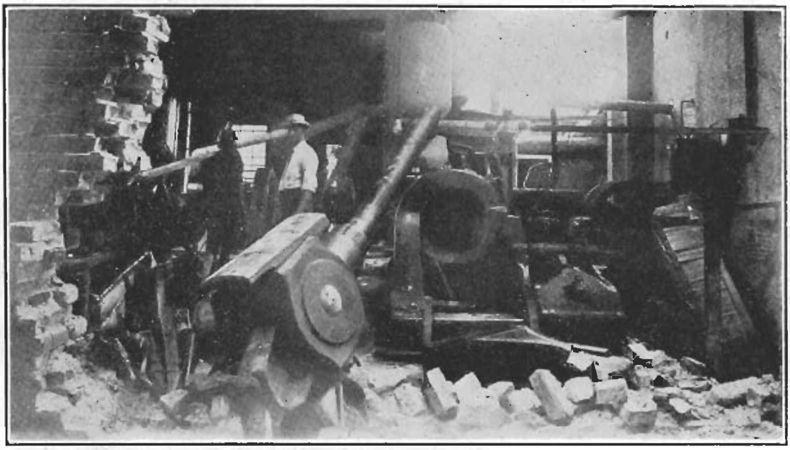
(a) Clogging of the machinery in the mill.

(b) Forcing an unusual number of machines at the same time.

(c) Careless or ignorant handling of friction clutches.

(d) If the engine drives electrical machinery, the overload may be produced by a short circuit.

(e) Sudden stoppage of the engine, as when the piston comes off and blocks the piston rod.



FLY-WHEEL EXPLOSION, ARKANSAS LUMBER CO., WARREN, ARK.
2 KILLED; 5 INJURED; PROPERTY LOSS, $9,000.

In many instances the overload is produced suddenly and causes the wheel to fail either by the torsional strain produced, or by the crushing strain due to the pressure of the belt acting against the rim.

Overspeed causes the wheels to explode by centrifugal force. By overspeed we do not especially refer to high normal speed, although many wheels are run normally at dangerous speed. We particularly refer to the accidental increase in speed beyond that for which the governor of the engine is set, and which is commonly called "racing." Racing may be produced by:

(f) Governor being improperly designed.

(g) Slipping or breaking of governor belt or of governor pulley.

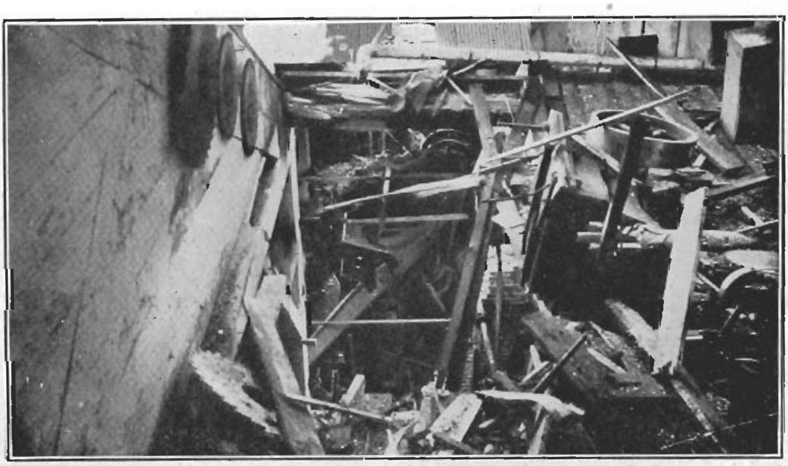
(h) Derangement of governor by internal or external causes, as when a stem or a rod gets stuck, or a ball gets broken off.

(i) Derangement of valve gear.

(j) Safety stops improperly set, or governor blocked.

(k) Sudden reduction of load, as when the main driving belt breaks or an armature burns out.

Besides the primary causes enumerated above, we may mention as contributory causes:



ANOTHER VIEW AT THE ARKANSAS LUMBER CO. SO MUCH DEBRIS IS STREWN ABOUT THAT IT IS DIFFICULT TO DETERMINE WHETHER THE PICTURE IS RIGHT SIDE UP.

(l) Defects in the design, material or construction of the wheel.

(m) Failure of some part of the engine, as when its bed breaks or its shaft fails, and throws the wheel against the side of the wheel-pit.

(n) An idler pulley or a driving pulley may break first and derange the governor or valve gear by hurling fragments into them.

In the case of a condensing engine, racing often continues until the wheel is disrupted, even after the engineer has succeeded in shutting off the steam.

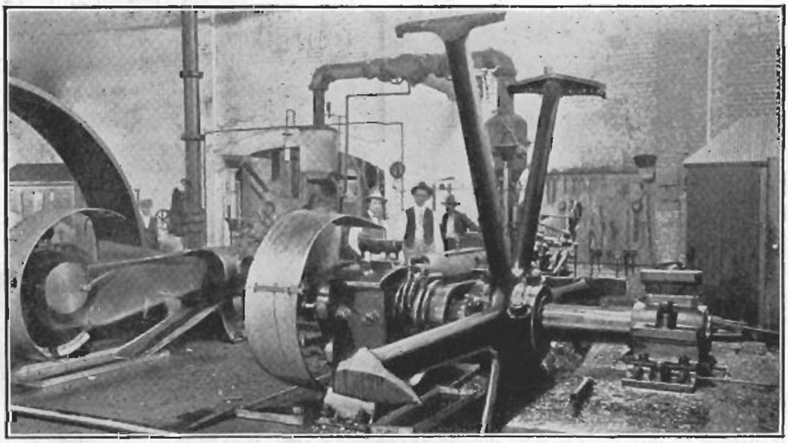
Unfortunately, when an engine starts to race the men in charge of machines in the mill shut them down, and the decrease in load causes a further increase in speed until the engine, entirely freed of its load, runs away and disrupts its wheel by centrifugal force.

STRESS IN FLY-WHEEL RIMS.

The stress in the rim of a fly-wheel, due to centrifugal force, will be better understood by a consideration of the formula

$$F = \frac{WV^2}{2.66}$$

from which the stress tending to burst the rim asunder may be obtained for a wheel made of any material and running at any speed.



FLY-WHEEL EXPLOSION MUSKOGEE GAS & ELECTRIC CO., MUSKOGEE, OKLA. PROPERTY LOSS, $3,159. WHEEL INSURED.

Stated in words, the formula means that if we multiply the *square* of the velocity of the rim in feet per second by the weight in pounds of one cubic inch of the material in the wheel, and then divide the product by 2.66, the result will be the force in pounds per square inch tending to burst the wheel.

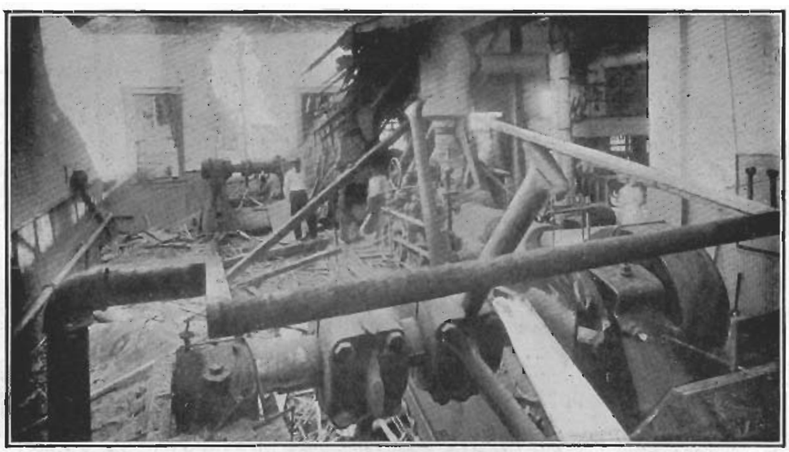
As a cubic inch of cast iron weighs about .26 of a pound, this gives for cast iron wheels

$$F = \frac{V^2}{10} \text{ approximately.}$$

That is, the stress tending to burst the rim of a cast iron wheel is one-tenth of the *square* of the velocity of the rim in feet per second.

From either of these formulæ it is seen that the stress in the rim of a wheel increases with the square of the speed, or, to put it another way, the margin of safety on speed is always the *square root* of the factor of safety on strength.

If the speed be tripled, for example, the stress in the rim becomes nine times as great as before; that is, with a factor of safety of 9 on strength, there is a margin of safety of only 3 on speed. It will be understood from this that the stress increases enormously for even a slight increase in speed.



ANOTHER FLY-WHEEL EXPLOSION AT THE MUSKOGEE GAS & ELECTRIC CO. THIS EXPLOSION OCCURRED THREE AND ONE-HALF YEARS AFTER THE ONE ILLUSTRATED ON OPPOSITE PAGE. PROPERTY LOSS, $4,153. WHEEL INSURED.

FLY-WHEELS AND BOILERS COMPARED.

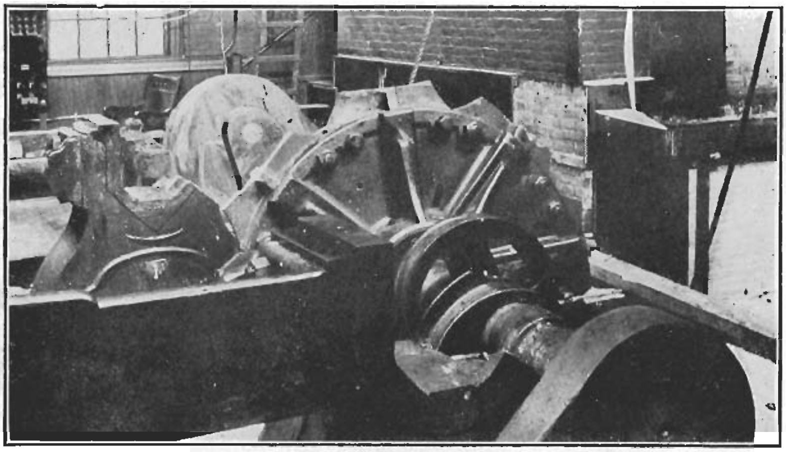
Comparing fly-wheels with boilers, it will be observed that while steam is always the primary cause of boiler explosions, speed is usually the primary cause of fly-wheel explosions. It would seem, therefore, almost as proper to speak of high "speed pressure" as to speak of high "steam pressure."

As a matter of fact, the influence of speed on fly-wheels is much the same as the influence of steam on boilers. Both produce radial forces whose resultants exert a tensile stress in the rim of the fly-wheels, or in the shell of the boiler, as the case may be.

In the case of boilers, *steam* exerts the radial force, acting on the shell of the boiler, and whenever the steam pressure becomes sufficient, the resultant stress bursts the boiler with great violence. In the case of fly-wheels, *speed* exerts the radial (centrifugal) force acting on the rim of the fly-wheel, and whenever the speed becomes sufficient, the resultant stress bursts the fly-wheel with great violence.

The term "explosion" may, therefore, be properly applied to either case.

While the influence of speed on fly-wheels is, as has been shown, much the same as that of steam on boilers, it should be borne in mind that when changes of speed and pressure occur,



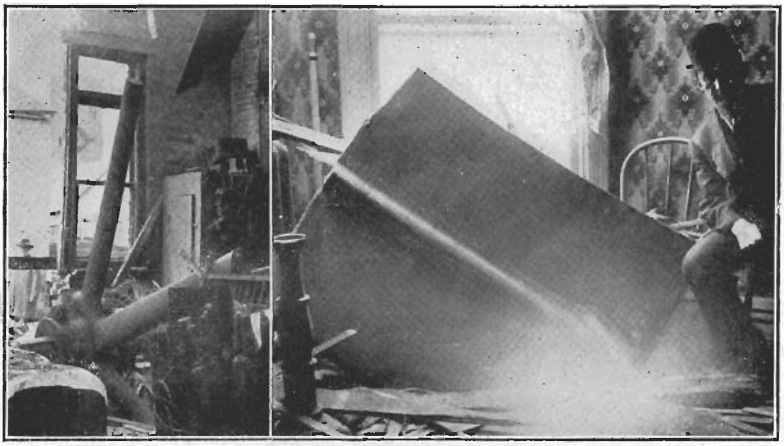
FLY-WHEEL EXPLOSION NEW ENGLAND COTTON YARN CO., NEW BEDFORD, MASS. ENGINE AND WHEEL COMPLETELY WRECKED.

the stresses produced in each case follow entirely different laws.

In the case of boilers, the stress in the shell increases proportionally with the steam pressure. Doubling the steam pressure, for example, doubles the tensile stress acting on each square inch of the shell. In the case of fly-wheels, the stress in the rim increases with the *square* of the speed. Doubling the speed, for example, *quadruples* the tensile stress acting on each square inch of the rim.

In the case of boilers, any increase in the thickness of the shell will allow a proportionate increase in the steam pressure that may be carried. If, for example, we should double the shell-thickness we could double the steam pressure. In the case of fly-wheels, increasing the thickness of the rim does not increase the allowable speed at which it may be run. The reason for this is that any weight added to increase the thickness of the rim increases the centrifugal force in exactly the same ratio.

It will be understood from the foregoing that while an engine-pulley or fly-wheel can be designed to successfully resist the torsional stress due to any load required of the engine, there is no possible way to overcome the centrifugal stress due to speed.



FLY-WHEEL EXPLOSION, NORTH SHORE ELECTRIC CO., WAUKEGAN, ILL. SLIPPING GOVERNOR BELT CAUGHT FIRE AND BURNED IN TWO, CAUSING ENGINE TO RACE. 2 KILLED; 2 INJURED. LOSS $30,000. SEGMENT CRASHED THROUGH ROOF AND INTO ROOM OF A HOTEL A BLOCK AWAY.

SPEED AT WHICH BURSTING OCCURS.

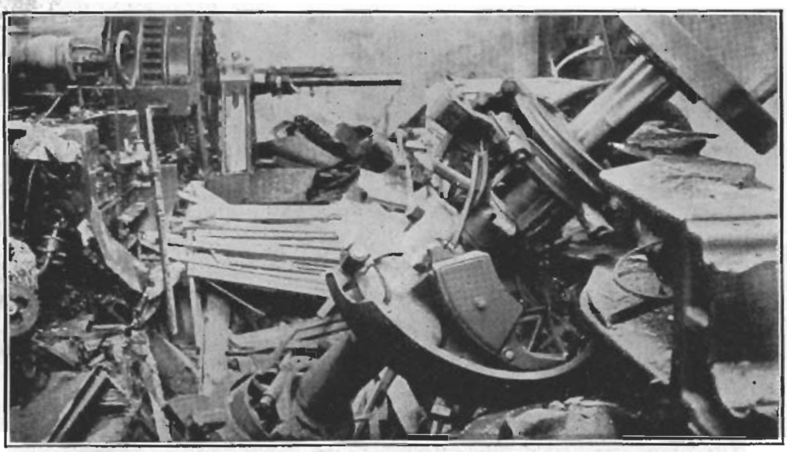
For a given material there is a definite speed at which disruption occurs, regardless of the amount of material used. This is not an uncertain theory, but a mathematical truth easily demonstrated, and is expressed by the formula

$$V = 1.63\sqrt{\frac{SE}{W}}$$

in which V is the velocity of the rim of the wheel in feet per second at which disruption will occur, W the weight of a cubic inch of the material used, S the tensile strength of one square inch of the material, and E the efficiency of the rim joint. (E = 1 for wheels without rim joints.)

Stated in words, the formula means that if we multiply the tensile strength of the material by the efficiency of the rim joint, divide the product by the weight of one cubic inch of the material, extract the square root of the quotient and then multiply this by 1.63, the result will be the rim speed in feet per second at which disruption will occur.

If, instead of the ultimate strength of the material, we take its safe strength, the result will be the rim speed in feet per second at which the wheel may be run with safety; the supposition being, however, that the wheel is made of homogeneous material, and is free from shrinkage strains.



FLY-WHEEL EXPLOSION, NORTH ADAMS GAS LIGHT CO., NORTH ADAMS, MASS. PROPERTY LOSS $7,539. WHEEL INSURED.

CAST IRON WHEELS.

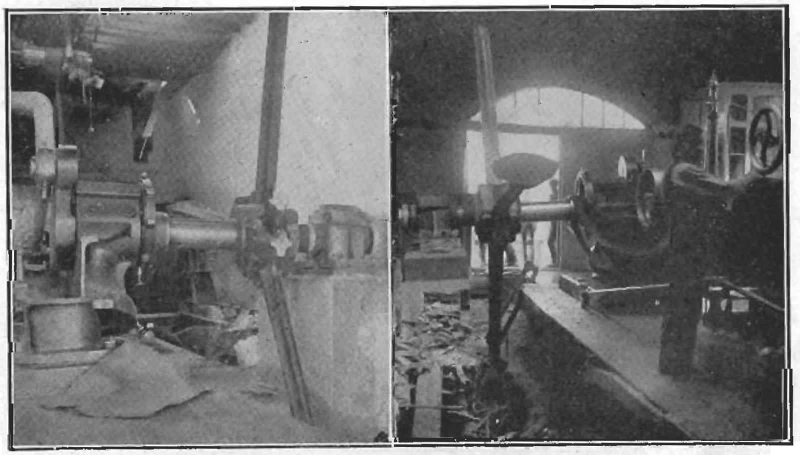
Applying the formula to determine the safe rim speed for cast iron wheels made in one piece, we would assume that, if the ultimate strength of small test bars were 20,000 pounds per square inch, we could depend upon having 10,000 pounds in large castings.

Using a factor of safety of 10 on this would give 1,000 pounds per square inch as the safe strength of this material. The weight of a cubic inch of cast iron is approximately .26 of a pound, so that for cast iron wheels we have

$$V = 1.63\sqrt{\frac{S}{W}} = 1.63\sqrt{\frac{1000}{.26}} = 100 \text{ feet per second,}$$

so that perfectly sound cast iron wheels made in one piece and free from shrinkage strains may be run with ample safety at a rim speed of 100 feet per second, which corresponds to about 1.15 miles per minute.

Small cast iron wheels are made in one piece. Large wheels are made in halves or sections to facilitate handling and transportation. It is common practice to make all engine wheels up to 8 feet in diameter in one piece; those between 8 and 16 feet in halves; and those over 16 feet in sections, the number of sections being usually equal to the number of arms in the wheel. Wheels are not often made larger than 30 feet in diameter, although 30 feet is, itself, a size frequently encountered.

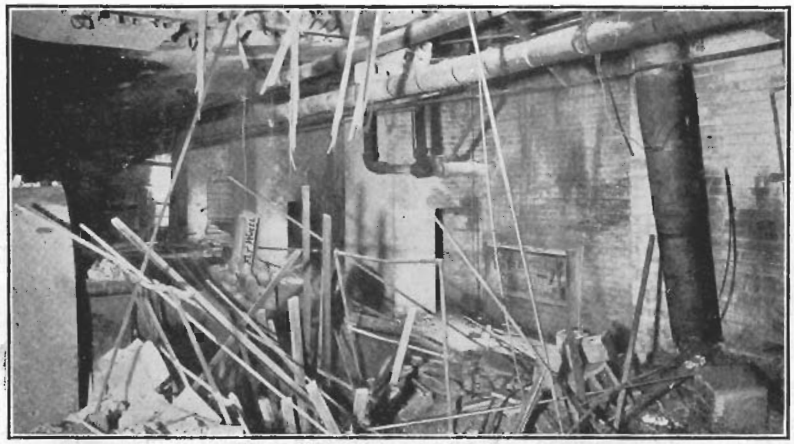


FLY-WHEEL EXPLOSION, NEW YORK & BATAVIA WOOD WORKING CO., BATAVIA, N. Y. TWO ENGINES WRECKED. LOSS $6,000.

Wheels smaller than 8 feet are frequently made in halves, either to avoid shrinkage strains or to enable them to be placed on their shafts without first having to take off other wheels. Frequently the hub only is split to obviate shrinkage strains.

This difficulty of shrinkage strains is a serious problem, and formerly led to the expediency of making the arms of small wheels in fantastic curves, often shaped like the letter "S." Shrinkage strains are produced by the unequal cooling of the arms and rim when the wheel is cast. If the mass of metal in the arm, for example, is proportionately greater than that in the rim—a frequent case with thin-rimmed pulleys—the rim, because of cooling and shrinking first, is pulled upon by the more slowly cooling arms, thus producing a bending strain in the rim and a tension strain in the arms.

The effect of this unequal cooling is not only to create enormous shrinkage strains in the wheel, but also to leave the metal at the juncture between arms and rim in a dangerously porous or honey-combed condition. The porous condition of the metal is caused by the tendency of the arms in cooling to pull away from the rim while the metal is in a plastic or half-molten state.



FLY-WHEEL EXPLOSION, BRADLEY ELECTRIC LIGHT, HEAT AND POWER CO., CLEVELAND, O. BELT BROKE AND WRECKED GOVERNOR; ENGINE RACED. LOSS $4,000. WHEEL INSURED.

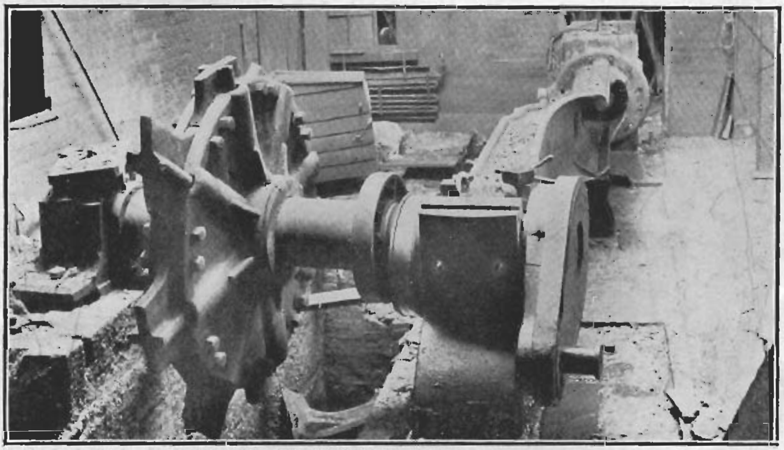
RIM JOINTS.

Rim joints are a constant source of danger and should receive careful consideration. Perhaps the importance of looking to the rim joint will be better appreciated when it is remembered that the usual bolted and flanged rim joints, located between the arms of sectional belt wheels, average a strength of only 20 per cent of the solid rim, and that it is not possible to design a joint of this kind having a strength greater than 25 per cent of the solid rim. By placing the joints in such wheels at the ends of the arms, instead of between them, an efficiency of 50 per cent of the strength of the rim may be obtained. The reason for this is that the centrifugal force of the heavy flanges and bolts is directly sustained by the arms, instead of being left free to act as a bending force on the rim.

In heavy, thick-rimmed balance wheels, where steel links are shrunk on to reinforce the joint, an efficiency of 60 per cent is possible, but this construction cannot be applied to belt wheels having thin rims. A higher efficiency of rim joint can only be obtained by making the rim of the wheel box or eye section.

SPEEDS THAT MAY BE CONSIDERED SAFE.

Assuming that the joints for solid rimmed wheels are designed to secure the greatest possible strength, and using the



FLY-WHEEL EXPLOSION, TENNESSEE FIBRE CO., MEMPHIS, TENN. ENGINE WRECKED; BUILDING DAMAGED; LOSS $2,150. WHEEL INSURED.

formula previously given, we have computed the allowable number of revolutions per minute for the several types and sizes of cast iron fly-wheels in current use. These are given in the table on page 24.

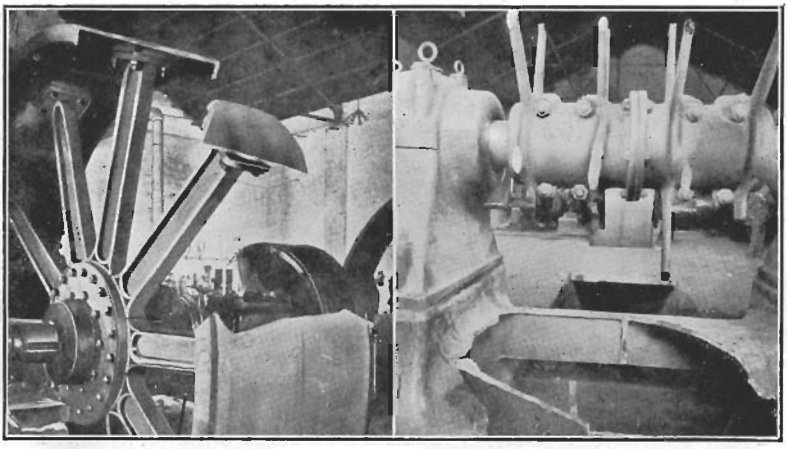
In preparing this table a margin of safety of 3 on speed has been allowed, so that if the revolutions there given be multiplied by 3, the result will be the number of revolutions at which disruption will occur.

WOODEN WHEELS vs. CAST IRON WHEELS.

Fly-wheels are subjected to a great variety of strains, the greatest of which is that due to centrifugal force. It is this strain that causes the majority of fly-wheel wrecks. The rim velocity at which centrifugal force becomes sufficient to burst a wheel made of any given material is, as has been previously stated, expressed by the formula

$$V = 1.63\sqrt{\frac{SE}{W}}$$

An inspection of this formula shows that the bursting speed is proportional to $\sqrt{\frac{S}{W}}$ and this means that the material which has the greatest strength for a given weight will stand the highest speed before going to pieces. Since wood



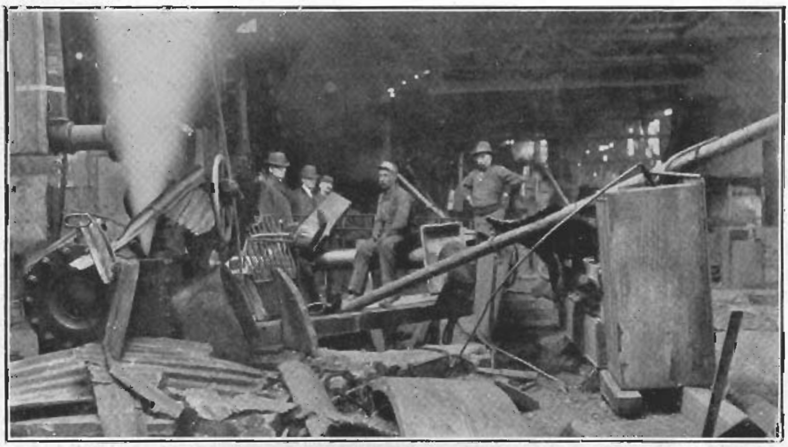
FLY-WHEEL EXPLOSION, LOS ANGELES STREET RAILWAY, LOS ANGELES, CAL. ENGINE WRECKED; DYNAMO SMASHED; STREET CAR DEMOLISHED; BUILDING DAMAGED.

possesses this quality, it is in the above respect a better material for fly-wheels than cast iron.

In comparing wheels having wood rims, however, with those having cast iron rims, it should be remembered that the wooden rims are built up of segments fastened together. These segments are sawed so as to obtain as much of the straight grain of the wood as possible, but the full tensile strength of the wood is never obtained. Partly for this reason and partly for others, a factor of safety of 20 is used for wood, where 10 would be used for cast iron. Twenty in this case is, however, only an apparent factor of safety, because a part of the tensile strength lost in sawing is included in this, making the real factor of safety, of course, less than 20.

Again, the wooden segments are put together to break joints so that the strength is further reduced one-half. This may be helped somewhat by arranging the segments so that only every third or fourth joint comes in line, instead of every other joint, but if this is carried too far, the contact surface on the sides becomes insufficient and weakens the shearing strength of the segments.

Applying our formula to hard maple having a tensile strength of 10,500 pounds per square inch and weighing .0283



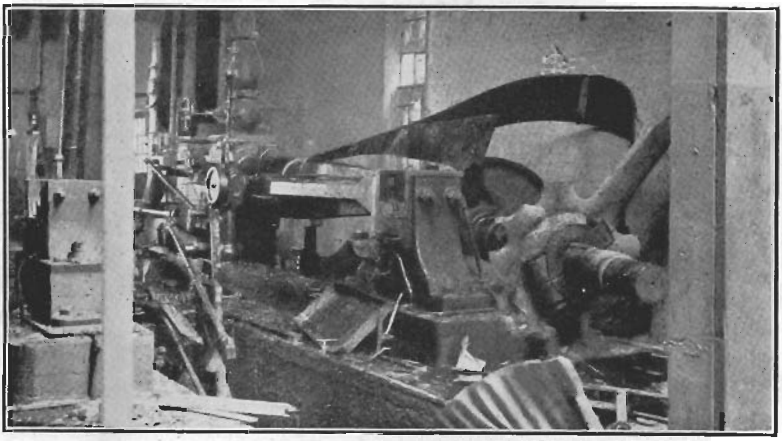
FLY-WHEEL EXPLOSION, NATIONAL ROLLING MILL CO., VINCENNES, IND. CYCLONE BLEW DOWN STACK WHICH FELL ON GOVERNOR, CAUSING ENGINE TO RACE AND BURST FLY-WHEEL BY CENTRIFUGAL FORCE. LOSS $1,900.

of a pound per cubic inch, we have, using a factor of safety of 20, and remembering that the strength is reduced one-half,

$$V = 1.63\sqrt{\frac{SE}{W}} = 1.63\sqrt{\frac{525 \times .5}{.0283}} = 154 \text{ ft. per second,}$$

so that a well-made maple wheel may be run with perfect safety at a rim speed of 154 feet per second, which corresponds to 1.75 miles per minute. Or comparing two wheels of the same diameter, one of cast iron and the other of maple, the number of revolutions per minute for the maple wheel may be 54 per cent greater than for the cast iron wheel. One hundred and fifty-four feet per second would not, however, be a safe rim speed for wooden wheels if made in halves or sections, on account of the weakness of rim joints.

After a disastrous fly-wheel wreck at the Amoskeag mills, Charles H. Manning, M. E., superintendent of the mill, designed and had constructed a large wooden fly-wheel. This wheel is 30 feet in diameter and 9 feet face. The rim is 12 inches thick and is built up of 44 courses of ash plank. The segments break joints and are glued and bolted together. There are two hubs and two sets of arms, twelve in each set and all of cast iron. The wheel weighs about 104,000 pounds, and was tested to a speed of 76 R. P. M., corresponding to a rim speed of 1.36 miles per minute.



FLY-WHEEL EXPLOSION, IOLA PORTLAND CEMENT CO., IOLA, KANSAS.
ENGINE WRECKED; BUILDING DAMAGED; LOSS $4,400.
WHEEL INSURED.

Since the construction of this wheel many large fly-wheels have been built of wood. They are satisfactory in service, and several large manufacturing concerns now make a specialty of wooden fly-wheel construction.

STEEL WHEELS BEST OF ALL.

Bringing into service again our formula for the bursting speed of fly-wheels, we see at once that steel is a superior material for the construction of wheels of large size. Unfortunately, the extreme cost of such wheels precludes their general adoption. Notwithstanding this, steel as a material has plenty of advocates, some engineers going so far as to say that it is the only fit material for large fly-wheels of high speed and high power.

In comparing steel wheels with wheels made of other materials it should be remembered that no wheel is ever stronger than its weakest section. As the rims of these wheels are built of plates cut into segments and riveted together, the weakest section is not necessarily at a rim joint, although usually so.

Assuming an efficiency of 50 per cent in the rim joint, and that no section of the rim has a net area less than 50 per cent

FLY-WHEEL EXPLOSION, SAYRE ELECTRIC CO., SAYRE, PA. ENGINE AND DYNAMO WRECKED. BUILDING DAMAGED. LOSS $8,210. VIEW SHOWS WHERE LARGE SEGMENT WAS HURLED THROUGH WALL. WHEEL INSURED.

of the gross area of the cross-section, and using a factor of safety of 10, steel having a tensile strength of 60,000 pounds per square inch would allow a safe rim speed of

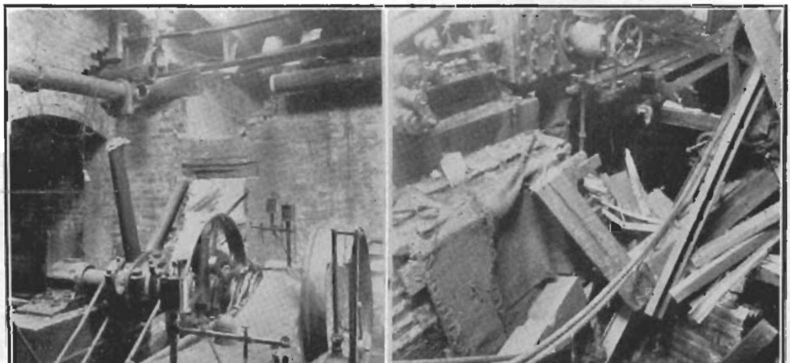
$$V = 1.63\sqrt{\frac{SE}{W}} = \sqrt{\frac{6000 \times .50}{.28}} = 188 \text{ feet per second,}$$

corresponding to 1.9 miles per minute. Thus steel wheels will stand a speed of 90 per cent greater than cast iron wheels.

Steel wheels may be divided into three distinct types, (1) those having centre and rim built up entirely of steel plates, (2) those having cast iron centre with steel rim, and (3) those having cast-steel centre and plate-steel rim.

An interesting steel wheel of novel construction was recently designed by Mr. Manning for the Amoskeag Manufacturing Co. The wheel has a cast iron centre and steel rim. The rim, however, is not built up of segments, but is made of rings or hoops, one within the other, all securely riveted together. In describing this wheel, Mr. Manning says it is stronger than steel wheels made of segmental plates and is also cheaper because the material is not wasted in cutting. The wheel is 15 feet 3 inches diameter, and 36 inch face.

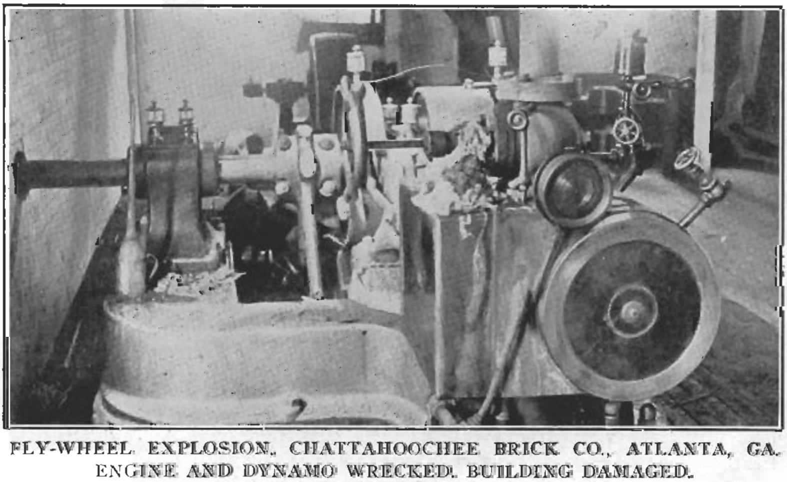
Steel wheels for extreme speeds have been constructed by winding steel discs with wire. Such a wheel is in operation in a rolling mill at Ladore, Wales, using the Mannesman process



FLY-WHEEL EXPLOSION, CHICAGO COATED BOARD CO., CHICAGO, ILL. ROPE DRIVE BROKE AND SMASHED GOVERNOR, CAUSING ENGINE TO RACE AND BURST WHEEL BY CENTRIFUGAL FORCE. LOSS $1,200. WHEEL INSURED.

of rolling tubing from the solid bar. As an immense amount of power is required for only a short interval, the wheel is subjected to heavy shocks as well as to high speed.

In constructing this wheel, two steel discs 20 feet in diameter were bolted to a cast iron hub. The outer edges of the discs formed a groove into which 70 tons of No. 5 steel wire was wound under a tension of 50 pounds. This wheel is operated at 240 R. P. M., which corresponds to a rim speed of 2.85 miles per minute. The wheel replaced by this one, and which was made of cast iron in the usual manner, broke at a rim speed of 1.42 miles per minute.



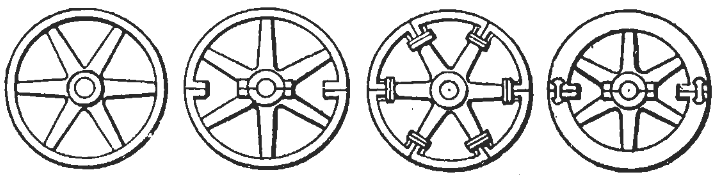
FLY-WHEEL EXPLOSION, CHATTAHOOCHEE BRICK CO., ATLANTA, GA.
ENGINE AND DYNAMO WRECKED. BUILDING DAMAGED.
WHEEL INSURED.

SAFE SPEEDS FOR CAST IRON FLY-WHEELS.

Margin of safety on speed, approximately three.*

Type of Wheels and maximum obtainable efficiency of rim-joint.

No joint. 1.00 — Flange joint. .25 — Pad joint. .50 — Link joint. .60



Diam. in Ft.	R. P. M. (No joint, 1.00)	R. P. M. (Flange joint, .25)	R. P. M. (Pad joint, .50)	R. P. M. (Link joint, .60)
1.	1910	955	1350	1480
2.	955	478	675	740
3.	637	318	450	493
4.	478	239	338	370
5.	382	191	270	296
6.	318	159	225	247
7.	273	136	193	212
8.	239	119	169	185
9.	212	106	150	164
10.	191	96	135	148
11.	174	87	123	135
12.	159	80	113	124
13.	147	73	104	114
14.	136	68	96	106
15.	128	64	90	99
16.	120	60	84	92
17.	112	56	79	87
18.	106	53	75	82
19.	100	50	71	78
20.	95	48	68	74
21.	91	46	65	70
22.	87	44	62	67
23.	84	42	59	64
24.	80	40	56	62
25.	76	38	54	59
26.	74	37	52	57
27.	71	35	50	55
28.	68	34	48	53
29.	66	33	47	51
30.	64	32	45	49

* If the revolutions given in the table be increased 20 per cent the margin of safety on speed will be reduced to *two and one-half;* if the revolutions be increased 50 per cent the margin of safety will be reduced to *two.*

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Accident..C. V. Everitt and W. H. Boehm
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Burglary.N. D. Sterling and W. P. Learned
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General Counsel.........Charles C. Nadal

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Mich.—O. P. Davies..............Detroit
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Mo.—J. H. Rush.............Kansas City
Mo.—H. R. McMurtrie & Co...St. Joseph
Mo.—F. E. Fowler & Co.........St. Louis
Mo.—R. A. Hoffmann............St. Louis
Mo.—Robert L. Dutton..........St. Louis
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N. J.—Harry A. Smith..........Hoboken
N. J.—Jos. M. Byrne Co..........Newark
N. Y.—Edgar E. Mueller..........Buffalo
N. Y.—Benjamin Sturges.......New York
N. Y.—E. E. Clapp & Co........New York
N. Y.—Metropolitan Office......New York
N. Y.—M. E. Wollf Co...........Rochester
N. Y.—S. F. Bagg...................Troy
N. D.—O. A. Webster........Grand Forks
Ohio—Chas. H. King............Cleveland
Ohio—Jas. R. Millikan..........Cincinnati
Okla.—Upsher and Upsher..Oklahoma City
Oregon—Seeley & Co., Inc.......Portland
Pa.—S. H. Pool..............Philadelphia
Pa.—John L. Rivolta...........Pittsburgh
Pa.—H. H. Campbell.............Altoona
Pa.—F. T. Jackson...................Erie
Pa.—J. J. McCarthy.............Scranton
R. I.—G. L. & H. J. Gross.....Providence
R. I.—John Casey, Jr..........Providence
Tenn.—Vance Powell & Co.......Memphis
Texas—I. Reinhardt & Son.........Dallas
Utah—Geo. W. Peck Co.....Salt Lake City
Utah—Tracy Loan and Trust Co., Salt Lake City
Va.—Robert Schaefer...........Richmond
Vt.—Jake Heyman.................Rutland
Wash.—Seeley & Co., Inc..........Seattle
Wis.—F. E. Delaney...........Milwaukee

ANNUAL FINANCIAL STATEMENT, DECEMBER 31, 1914

ASSETS

Stocks and Bonds	\$8,292,317.71
Real Estate	1,368,893.45
Cash in Banks and Office	616,792.15
Gross Premiums in course of collection (not overdue)	1,394,398.05
All other Assets	186,328.17
	\$11,858,729.53

LIABILITIES

Reserve for Unearned Premiums	\$4,915,445.39
Liability Losses { Claims resisted for policy-holders	1,008,114.00
Liability Losses { In process of adjustment	741,886.00
Steam Boiler Losses, in process of adjustment	21,528.00
All Other Losses, in process of adjustment	926,057.80
Commission on Premiums in course of collection	362,395.34
All other Liabilities	344,182.19
Reserve for Contingencies. Not required by law \$500,000.00; Capital Stock 1,000,000.00; Net Surplus 2,039,120.81 } Surplus to Policy-holders	3,539,120.81
	\$11,858,729.53

Amount of All Losses Paid to Date, December 31, 1914....\$48,580,800.32

1876 - 1915

The Fidelity and Casualty Company of New York

92 Liberty Street (Just West of Broadway)

THIS COMPANY GRANTS INSURANCE AS FOLLOWS:

BONDING DEPARTMENT

1. FIDELITY—Against loss by defalcations of persons in positions of trust.
2. SURETY—Against loss by defaults of principals under bond.

ACCIDENT DEPARTMENT

1. PERSONAL ACCIDENT—Against death and loss of time caused by accidental bodily injuries.
2. HEALTH—Against loss of time caused by sickness.

PLATE-GLASS DEPARTMENT

Against loss by accidental breakages.

LIABILITY DEPARTMENT

1. EMPLOYERS' LIABILITY—Against damages for personal injuries sustained by employees of manufacturers, miners, contractors, etc.
2. EMPLOYERS' PUBLIC LIABILITY—Against damages for personal injuries sustained by persons other than employees through industrial operations.
3. TEAMS—Against damages for personal injuries caused by horses and vehicles.
4. AUTOMOBILE—Against damages for personal injuries caused by automobiles.
5. WORKMEN'S COLLECTIVE—Collective personal accident insurance for workmen in industrial establishments.
6. PHYSICIANS' AND DRUGGISTS' LIABILITY—Against damages claimed by patients or customers.
7. OWNERS' AND LANDLORDS' LIABILITY—Against damages for personal injuries sustained by persons on their premises.
8. PASSENGER ELEVATORS—Against damages for personal injuries sustained by passengers.
9. WORKMEN'S COMPENSATION—Against compensation payable to employees under Workmen's Compensation Acts on account of personal injuries.

BOILER AND FLY-WHEEL DEPARTMENT

1. STEAM-BOILER—Against, 1st, the direct loss of property; 2nd, damages for property of others destroyed; 3rd, damages for personal injuries: caused by explosion of steam-boilers.
2. FLY-WHEEL—Against, 1st, the direct loss of property; 2nd, damages for property of others destroyed; 3rd, damages for personal injuries: caused by disruption or explosion of fly-wheels.

BURGLARY DEPARTMENT

For bankers, merchants, householders and others against loss by burglary.

¶ **The Company, in its Bonding, Boiler, Elevator and Fly-Wheel Departments, employs skilled inspectors, makes thorough-going inspections, and reports thereupon to the assured**