Chapter IV

SOME PRACTICAL APPLICATIONS OF THE PHOTRONIC CELL

The preceding chapter was intended to give the why and how of PHOTRONIC cells. We saw that the cell worked because, when light struck its sensitized surface, electrons were liberated. These electrons in motion then become an electric current. We also saw just how this generated current found its way into the external circuit and how that delivery was modified by light, external resistance, temperature, etc.

Naturally, the next step is to find ways to use such cells to our best advantage. Some will be immediately apparent; others will appear as the characteristics of the cells are studied and as our needs suggest. And even some things about the cells that, at first glance appear to be handicaps, turn out to be almost indispensable features for certain purposes.

Take for example the way in which the linear relationship between current and light intensity suffers when the external circuit has a high resistance. If that did not happen, and we wanted a meter with which to read brightness ranging from that of semi-darkness up to that of the sun, it would be necessary to have a scale feet in length. As it is, with proper external resistance we can keep the low values spread out sufficiently for accurate reading and compress the higher values into a space made only wide enough for the accuracy required in their indications.

Our eyes look upon things in a very definite manner. We live in a dream world, seldom seeing things as they actually are. Consequently, in many cases absolute reality has no meaning for us. Therefore, when we use a device of any sort, there are times when we are not interested in having it tell us bald facts—we want it to interpret things in the language we know. For instance, we want light measured in terms of visibility—not in terms of the energy being dissipated.

Chemical and physical forces, on the other hand, look at grim reality. They act according as things are—not as they appear to be. Therefore, when we want to control such forces, we require a device that will tell us how those things see and feel—our own reactions are of no consequence.

PHOTRONIC cells are versatile enough to come to our assistance in both cases. They provide the common denominator that links us to that other world of blind forces; they tell us what is happening there in words we may understand.

And what better way is there of illustrating their helpfulness than by giving concrete examples? than by actually pointing out how we are using them this very day? The PHOTRONIC devices manufactured by Weston will serve us admirably as cases in point; they will show us how to lay our hands on these uses by showing how they are actually being used.

Illumination Measurement

Perhaps the simplest PHOTRONIC device is the direct combination of cell and indicating instrument that gives us what is known as the Illumination Meter (Weston Model 703)

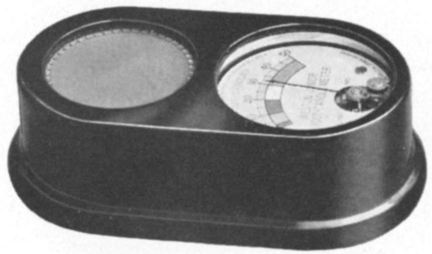


Fig. 11. Weston Model 703

This device measures the intensity of light. It takes advantage of the fact that, for external circuits of low resistance, the PHOTRONIC cell delivers current practically in proportion to the illumination upon it. Connect a cell directly to a microammeter and you have the instrument at once. All that remains is to mark off the meter scale in terms of foot-candles or any other illumination unit desired.

In such a combination the range of light intensities measured must be restricted if high reading accuracy is to be had along with convenient scale size. This would be a limitation were it not for the fact that one meter scale plate can be marked for several ranges, and the scope of the meter broadened by the use of proper shunts for higher intensities.

These latter have the normal functions of all shunts: they simply allow only a portion of the total current to pass through the sensitive meter. However, the portion going through the movement bears a very definite relation to the total, and may be so arranged that one-tenth passes through while the other nine-tenths is "by-passed" through the shunt.

In this way, where the total current would be so large as to drive the pointer off the scale, the use of the shunt prevents this without restricting the cell to a lowered delivery. When the proper shunt is connected, for example, and the pointer goes up to the mark which indicates 5 foot-candles, the real intensity is simply ten times that indicated value, or 50 foot-candles. Another shunt would make it 500 or 5,000—all according to the way it was made.

Suppose, on the other hand, when dealing with very dim light, the cell does not generate enough current to drive the pointer a decent readable distance. Instead of using shunts to cut down the current flowing through the meter, we now use extra cells, connected in parallel, to give us more.

In one Weston Illumination Meter (Model 603) two cells are used in just this way. They are mounted in a holder located at the end of a flexible cable so that the "light target" can be used some distance from the meter. This makes it possible to reach some places otherwise inaccessible. It also prevents the introduction of sizeable errors which might be caused by the meter reader either shadowing the cells or reflecting additional light upon them from his clothing, hands, etc.

Fig. 12. Weston Model 603

Exposure Meter

To get a good picture the photographer must know the amount of light reaching his film. In the past he squinted at his surroundings and then guessed at the proper diaphragm opening and camera shutter speed that would do a good job. His eyes guided him in his guess and, because they are such poor estimators of such things as light, his guess

was very often wrong—and the picture he wanted or needed most was a rank disappointment after development. His eyes miscalculated—but the film did not. "So much light, such and such a picture" says the film—and it means it!

But the PHOTRONIC cell, made up into a device called an Exposure Meter (Weston Model 650) has done away with the need of such guesswork. This meter views the scene to be photographed and at once tells the camera operator just what diaphragm opening and what shutter speed is needed to give the type film he is using the right amount of light for a good picture. It doesn't guess; it knows!

Fig. 13. Weston Model 650 Exposure Meter

At first thought it might seem that an Exposure Meter is as simple to make as an Illumination Meter. There is one thing we must not forget, however; the camera is not interested in a large hemispherical area from which light is proceeding, but is concerned merely with a very restricted field taking in, as far as possible, only the subject to be photographed.

Cameras in general admit light to the lens through a cone of less than 60° angular extent. If the Exposure Meter is to guide the camera, then its field must also be limited in the same way. This is accomplished by using a properly designed "baffle" between the cell and the scene to be measured. In the Weston meter this baffle is a metal disc pierced with holes in such a way as to limit the cell's vision.

But this restriction of the field means something else—and this is important. The Exposure Meter reads brightness, candles per square foot for example, rather than merely light intensity. In other words it reads the average intensity of light emitted per unit area of the scene it looks upon; it tells, for instance, the average of the light intensity

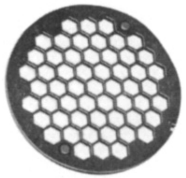


Fig. 14. Light Baffle in Model 650

proceeding from every square foot of the space contained within the base of that 60° cone whose apex is at the cell.

There is a very simple way to demonstrate the fundamental difference between the Illumination Meter and the Exposure Meter. Suppose we consider as our total amount of available light that which is reflected from an evenly illuminated wall as a source. If, from, let us say, a distance of ten feet, we advance the target of an Illumination Meter toward that wall, the meter readings will increase as we approach the wall.

But what about the Exposure Meter? At ten feet that meter sees only a section of the wall, a section representing the area of the base of a 60° cone. As the wall is approached, the area of this base grows less and less—and to exactly the same degree that the Inverse Square law causes the light intensity from that diminishing area to increase. The product of the area and the light intensity, although both are changing, remains a constant value. In other words, if the meter reads candles per square foot and if its view includes one-half of a square foot or two square feet, it still tells the camera how much light is proceeding from that wall per single square foot. Because the light emitted by each square foot of the wall is naturally a fixed quantity, therefore the Exposure Meter reads the same at 5 feet distance as at 10 feet or at any other distance, provided of course the area of uniform brightness is large enough to be included in the 60° cone.

Perhaps a mathematical explanation will help make this clearer.

Suppose we place an Exposure Meter so that its cell is at a point "C" 10 feet distant from the wall of which we spoke. For simplicity let us assume that the cell is parallel to the wall and that the line "CO" (see Fig. 15) represents the perpendicular distance between "C" and "O" (Remember that the angle of vision of the cell, "ACB" is restricted to a definite angle.)

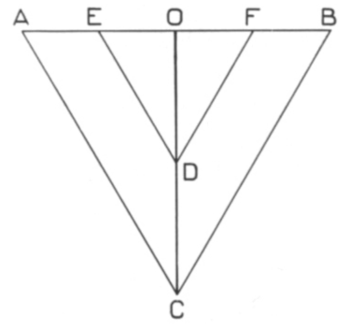


Fig. 15

With the meter at "C" the angle of vision will include the circular area of the base of a cone whose projection is "AOB" Let us assume that under these conditions the Exposure Meter gives a reading indicating 100 light units.

Now, with everything else as before, suppose we move the meter so that the cell is at "D" and that the distance "OD" is only five feet, or ½ the former distance "OC" Then, our geometry tells us, we have caused the radius of the new circular area of vision "EOF" to be exactly ½ the radius of the former area, "AOB"

We also know that the areas of circles vary as the square of their radii. In other words:

$$\frac{\text{area "EOF"}}{\text{area "AOB"}} = \frac{\pi \times (\text{radius of "EOF"})^2}{\pi \times (\text{radius of "AOB"})^2} = \frac{(\text{radius of "EOF"})^2}{(\text{radius of "AOB"})^2}$$

Since we have caused the radius of the area "EOF" to be ½ that of "AOB" we see that:

$$\frac{(\text{radius of "EOF"})^2}{(\text{radius of "AOB"})^2} = \frac{(\frac{1}{2})^2}{1} = \frac{1}{4}$$

In other words, by moving the meter from "C" to "D" we have cut its area of vision to one-fourth its former value. In consequence, the light affecting the cell will be only one-fourth what it was before.

But, when we moved from "C" to "D" we also decreased the distance from the wall to ½ its former value. Now the Inverse Square Law says that this will mean an increase of very definite proportions in the light intensity. Our light will vary as the square of the distance. Hence the intensity of the light at "D" will be $\frac{(2)^2}{(1)^2}$ or 4 times what it was at "C"

Summing up these effects we see that, where our meter read 100 light units in its first position, due to the changed area of vision and the accompanying change in light intensity, our meter will now read:

$100 \times 1/4 \times 4 = 100$—exactly what it did before!

And no matter what other area the meter is made to view, it will read precisely the same—so long as the illumination power of the wall does not change and the full area of vision of the meter is embraced by that wall.

While the camera's requirement, that the meter read the brightness of the scene to be photographed, complicates the problem of the designing engineer, still the use of such a meter is not at all complicated.

Mounted upon the case of the Weston meter are two exposure discs. The setting of one takes care of the "film speed" or the sensitivity of the emulsion on the particular film you are using. Once this setting is made, it need not be changed unless some other kind of film is placed in the camera. The other exposure disc, set according to the reading of the meter, tells the proper "f" stop or diaphragm opening and the shutter speed necessary for the subject to be photographed correctly.

The meter reading is gotten by placing the Exposure Meter in approximately the position of the camera lens, with the cell directed toward the subject whose picture is to be taken. Care must be exercised not to include too much sky, but to measure as nearly as possible only the light reflected from that subject. The pointer then gives the necessary information for setting the second calculator disc.

Over the meter's name plate there is a table of film speeds. These do not necessarily correspond to speeds as given by the film manufacturers. The reason for this is that the manufacturers' designations are in terms of the eye while the Weston speeds are in terms of the PHOTRONIC cell which is being substituted for the eye.

Daylight Recording

Especially in large cities, it is somewhat of a problem for the power companies to maintain just a sufficient supply of electricity for their customers. They know quite well what the expected consumption will be at different hours of the day, and they prepare for it by cutting in or out a certain number of their generators. When evening approaches, in thousands of places, electric light buttons will be pushed for artificial light. More generators have been set going to handle this peak load. Everything works smoothly so long as the power company knows what to expect.

Now some device that would warn the power companies of impending rapid changes in demand would make the task easier. The PHOTRONIC cell is just such a thing. An "electric eye" scanning the heavens and recording changes in daylight intensity, would give plenty of warning so that, when a dust cloud or very heavy smoke from a large oil fire or a storm approached, everything could be in readiness.

The flexibility and detailed watchfulness of such an "electric eye" is amply demonstrated by the fact that, in scientific observations during the eclipse of the sun in 1932, PHOTRONIC cell light-recorders at Magog, Canada, showed that the light had fallen from normal intensity to as low as 0.008 foot-candle.

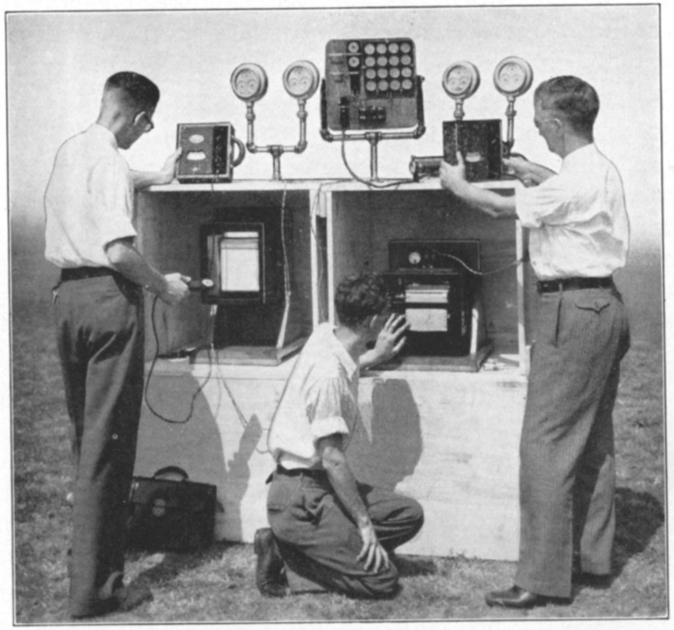


Fig. 16. PHOTRONIC equipment used at Magog, Canada, to measure the eclipse of the sun in 1932

Many laboratories are equipped with pyrometer recorders or similar devices. An interesting insight into the way our daylight varies over the period of a day, and from day to day, may be gotten by attaching a PHOTRONIC cell to one of these recorders. If possible, the cell should be exposed to light coming from the north sky, since this furnishes the best average for conditions of general illumination received on the Earth.

Illumination Indicator

Where the proper level of light in a workroom or laboratory is maintained by hand control, a device for telling when artificial light is needed can be made by connecting a PHOTRONIC cell to almost any properly designed standard type of instrument. The scale should be calibrated in light units and the meter mounted on the switchboard or other panel where it will be exposed to the prevailing illumination.

Differential Circuits

Under certain conditions we are not interested in the total current generated by a PHOTRONIC cell under different influences and at different times. Sometimes we are much more interested in the change in that total. By using what is known as a differential circuit we can discern the change directly.

If we take two cells and "buck" them in a proper kind of circuit, then, upon illumination, a meter connected to them will indicate the difference in their respective light sources. Let us suppose that we train a light upon a surface that will reflect upon both cells. Now, if over the part of that surface which is reflecting the light to one of the cells we place a piece of colored material, the light reaching that one cell will be cut down and the meter reading will indicate the different reflecting qualities of the two kinds of surface.

Such a device can be used as a crude method for color matching. By properly placing a "standard" piece of cloth, let us say, in front of one cell and various other pieces, one at a time, in front of the other one, we can tell when the "unknown" matches the "standard" because then the meter reading will be zero. Pieces which do not match the "standard" will cause the meter to depart from zero according to how much they are unlike that "standard"

In a case like this, where the original light source (not the reflecting pieces of cloth) is controlled by an ordinary lighting line, changes in the voltage on the lamps will not affect the matching job because changes in the light resulting from these voltage changes will affect the cells each in the same way. These duplicated changes will automatically balance out the error that would otherwise be introduced.

Another advantage in this kind of hook-up is that the small difference in current can be spread out over the whole scale of the meter. Having a large scale, very small differences are at once read off accurately.

Relays

The use of PHOTRONIC cells for control purposes almost inevitably makes it necessary to consider that most useful device, the relay.

Relays, are simply mechanical switches actuated by electrical energy. When they are energized by some primary source, such as photocells, batteries or the "line" they mechanically open or close a secondary set of contacts which then act to open or close a secondary circuit, such as the current supply to motors, lights and so forth.

Of course, relay design involves many considerations arising from the particular use to which a certain relay is to be put. In this booklet we cannot be concerned with the details. However, since we must use relays so frequently, we should have an understanding of the larger aspects of their make-up and operation.

There are two main types of relays, depending upon the principle of operation. One type is based on "solenoid" action. In this case an electromagnet is energized by some primary source, whereupon it pulls some sort of "plunger" device into position. This plunger, in some mechanical way, then opens or closes a set of contacts which acts as a switch for the secondary, or controlled, circuit.

There are several ways of closing the secondary circuit. The plunger may carry, directly attached to itself, a metal contact which it presses firmly against some fixed contact. Or, the plunger may act simply as the means of tilting a mercury switch so as to open or close another circuit.

These mercury switches are glass tubes containing mercury and into which protrude two electrodes forming the two sides of some "line" to be controlled. In a horizontal position the mercury makes contact between the electrodes; tilted, the mercury flows away from one electrode and opens the circuit.

The solenoid type of relay requires comparatively large wattages for operation. Consequently, in answer to a demand for greater sensitivity, the permanent magnet "moving coil" principle, used in most electrical measuring instruments was adapted to the relay.

In this type of relay a moving coil is mounted, as usual, within the field of a permanent magnet; to the coil is attached a proper pointer. In operation, some primary source sends current through the coil which then tends to rotate, carrying the pointer through some definite degree of deflection. This pointer then serves as a means for making contact with another suitably mounted contact and opens or closes some secondary circuit in exactly the same manner as did the plunger in the solenoid relay.

These sensitive relays have the advantage of requiring very little current to deflect the pointer sufficiently for operating the secondary contacts. However, they also have this disadvantage: the "torque" or force of rotational effort, of the coil is necessarily small due to the small amount of energy received from the primary current supply. This weaker torque means that the pointer is not able to exert very much pressure against the contacts of the secondary circuit and, consequently, there is a tendency toward "chattering" or repeated rapid opening and closing, which burns the contacts due to induced arcing. As a result of this, satisfactory operation of sensitive relays involving heavy secondary loads is difficult, for relays made in the ordinary manner, but a novel type recently produced overcomes this defect and is described in the following paragraph.

Sensitrol Relay

Weston has developed a whole line of relays for various purposes, but one in particular, the Sensitrol, is unique in its operation. The Weston Sensitrol Relay employs the moving-coil principle but with a slight, but very important, difference.

In the Sensitrol we have the coil and pointer as usual, but the pointer is not depended upon to exert any pressure upon the secondary contacts. Mounted upon the pointer there is a small soft-iron "rider" When the pointer swings the predetermined distance, this rider suddenly swings over into the field of influence of a powerful permanent magnet which also acts as secondary contact. In this way the rider is snapped up and held firmly in place and chattering is avoided.

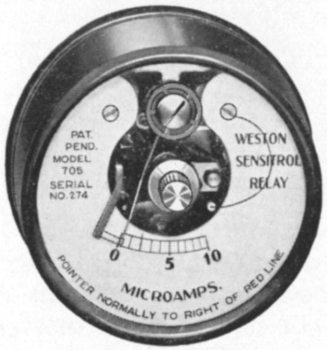


Fig. 17. Weston Sensitrol Relay

The advantage of the Sensitrol relay is obvious when we consider that 1 microampere through the coil can be used to properly control as much as 50 milliamperes at 110 volts. The Sensitrol combines the advantages of sensitivity, with necessarily low activating force, with high amplification, or control of large wattages by means of small ones.

Relays are very often used in "chain" arrangements. In a case where more than the 5 watts capacity of the Sensitrol must be controlled by very small currents such as those generated by the PHOTRONIC cell, et cetera, these small currents are used to energize a Sensitrol relay whose secondary circuit can control sufficient wattage to act as energizer for the electromagnet of a solenoid type relay. The solenoid secondary contacts can then handle the load which it is desired to control.

Illumination Control

The following picture shows how the relay is substituted for the meter in control work. This Weston Model 709 consists of a small panel on which are mounted two Sensitrol Relays, an induction motor and a mercury switch. The affair is used to automatically control illumination either indoors or outside—with proper protection against the weather, of course.

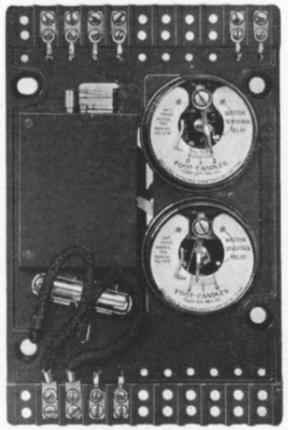


Fig. 18. Weston Model 709 Illumination Control

It is used in this way: A PHOTRONIC cell, or group of cells, act as energizer for one of the relays. When the current from that cell falls to a predetermined level, the one relay snaps shut, works the mercury switch and turns on the artificial lights.

As soon as this happens, the induction motor operates a switch of its own which transfers the light-target, the PHOTRONIC cell assembly, over to the other relay. So long as the controlling light remains low, nothing happens but, in the case of outdoors, when the sun comes up at dawn, the needle of the second relay begins to swing higher and higher. When the light reaches a fixed level this relay snaps shut, operates the mercury switch and turns the artificial lights off again. And then the whole cycle is repeated.

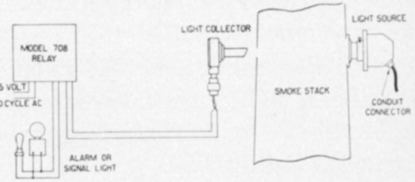
Each relay can be set for a different light level. For instance, in a city, safety may require that the street lights be turned on before the daylight gets very weak. In the morning, however, with the streets deserted and traffic at a very low ebb, the dim light of early dawn may be all that is necessary. By having the relays set for different intensities there is no needless waste of current.

Density Control

The flexibility of the Sensitrol makes it possible to use this relay for density control. It can be set so that it functions when light changes by a certain amount; there is no need for having the actuating PHOTRONIC cell fully illuminated one moment and then entirely darkened the next. The ability to function on variation in light allows of controlling such things as smoke in a stack or the relative cloudiness of chemical solutions.

Weston has turned this to practical account in its Smoke Alarm. Excessive smoke belching from the stack is expensive for two reasons. First, every bit of that black smoke represents unburned fuel that must be paid for. Second, most communities have Smoke Abatement Commissions which levy fines upon those who contaminate the air unnecessarily with soot. Either one of the reasons is sufficient to demand control.

With the Smoke Alarm, a PHOTRONIC cell is mounted opposite a light source in the stack and is connected to a calibrated Sensitrol Relay in the fire-room. As the density of the smoke increases the relay pointer indicates this by swinging away from a point marked "Clear" and over toward another marked "Smoke" If this warning is not heeded by the fireman, when the smoke reaches the legally tolerated limit the relay snaps shut and starts one or more gongs clanging. If one of the gongs is in the superintendent's office it doesn't take the fireman long to attend to his fires.



Installation diagram of the Smoke Alarm

Fig. 19. Weston Model 708 Smoke Alarm

Another density-control job arises where large quantities of movie or other film are developed. As you know, developing involves washing much unused silver salt from the film. Silver is expensive and in these establishments an important part of the work is recovering this precious metal from the used baths.

The PHOTRONIC cell and the Sensitrol Relay took over the task of controlling the reclamation. In this operation the silver is precipitated from the solutions by adding chemicals to them. The amount of these chemicals needed is determined by the relative cloudiness of the silver laden "hypo" a continuous sample of which passes through a glass tube between the cell and a light source. As the light on the cell varies the information is carried to the Sensitrol which then operates a valve controlling the addition of the precipitant.

In general, the efficiency of chemical processes has been found to depend greatly upon the effective acidity or alkalinity of the solutions. PHOTRONIC cells and Sensitrol relays, by similar density checks, now control this "hydrogen-ion concentration" also.

Color Matching

Under "Differential Circuits" one method of using the cell for color matching was indicated. There are, of course, many times when matching or sorting, based on color differences, is quite necessary. One of particular interest concerns coffee roasting.

Aside from getting the proper kind of coffee, the roaster, if he is to supply you with a palatable brew tomorrow morning and every morning, must be sure that there is just the right degree of roasting and that every batch receives the same treatment.

Today many pounds of coffee are watched over by PHOTRONIC cells. A light is directed upon the beans as they pass a window in the roaster. The quality of the light reflected from them depends upon how well done they are. This reflected light strikes the cell and, when the beans are exactly the right color, they are ejected from the roaster.

Industrial Control

In industry and trade there are many cases where automatic control would mean less work as well as the elimination of guesswork. There are a number of ways to effect this control but the one substituting light for mechanical arms has distinct advantages.

A ray of light has no inertia; it doesn't have to stop and think before it gets going. It has no lag; it stops in a split second. It can be terminated at any desired point. It will not mar or tear even the most delicate things. It has no weight. It is produced with the utmost ease.

Therefore, to apply this excellent servant to industrial control, Weston has made the Industrial Control Relay Assembly. It includes equipment designed to handle a whole line of control problems which have a fundamental sameness though differing in details.

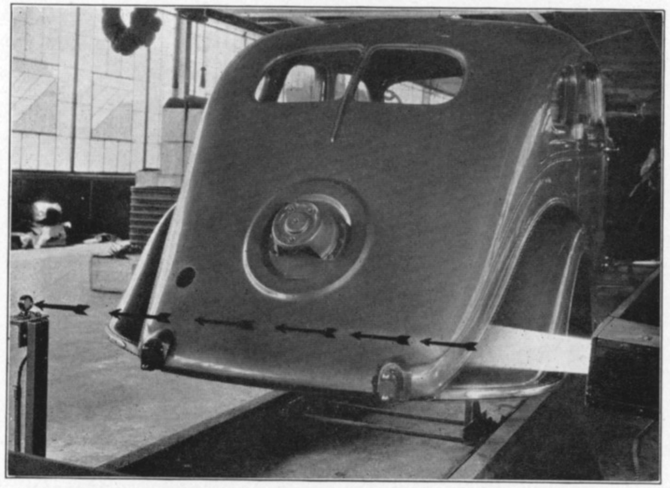


Fig. 20. Conveyor Controlled with a PHOTRONIC Relay

At the point where the operation to be controlled is located, there need be nothing but the PHOTRONIC cell and the light source. The relay assembly may be placed wherever desired. It is provided with a small transformer and a rectifier so that it can be plugged in on any ordinarily available power supply.

The relay requires 6 volts d-c for its operation. By means of the transformer the line voltage is stepped down to this level. The rectifier does the work of changing the a-c to d-c.

Counting

One of the general uses of this assembly is for counting things such as packages of cereal, bags of flour, pieces of metal and so on. The steel industry has made use of it to count steel plates as they come from the rolls.

In this case the regular working light is used to illuminate the cell which is mounted near the base of the mill. Every time a sheet passes from the rolls, the light is cut off and the cell trips a counter. This counter may be located anywhere and furnish information directly to those interested.

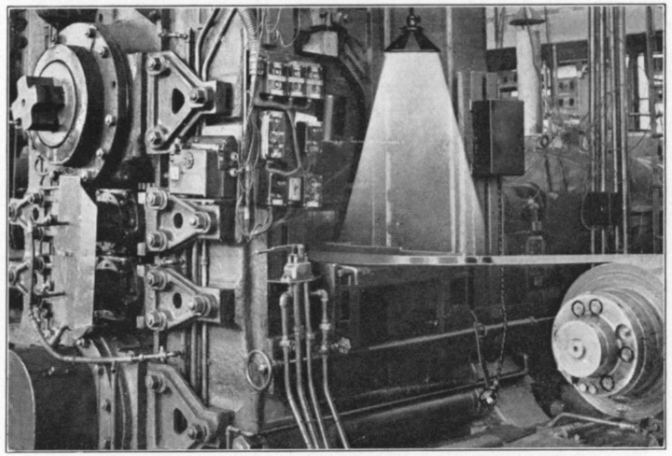


Fig. 21. Counting Steel Sheets with a PHOTRONIC Relay

Door Control

In a large modern garage modern methods must be used. Where many cars are coming in and going out during the day, some way must be found to open and close the doors without wasting too much time. Right there another use for the Industrial Control Relay Assembly presents itself.

As a car approaches the doors, the ever-vigilant cell sees to it that they are swung open. After the car passes through, it closes them again. There is no waiting, none of the delay involved in manual labor and—an important feature in a large building—no waste of fuel due to excessive cooling of the interior incident upon slow opening and closing of doors.

The modern railroad terminal also uses this control. In a big city like New York, commuters rush for trains or hurry to get out into the street. Many times they are loaded down with bundles of all sorts. The PHOTRONIC cell sympathizes with them and, as they approach the exit and entrance doorways, the doors are pulled open, the person passes through, and the doors close again.

Fig. 22. Door Controlled by a PHOTRONIC Relay

Safety Devices

We have seen how the PHOTRONIC cell and relays keep processes in line, do counting jobs and add to human comfort. But they do more than that: They insure the safety of human limbs and lives.

Many a time a punch-press operator, in a hurry to finish his work, has pressed a lever before getting his hand out from under the dreaded punch. His one slip, his one error in judgment has instantly moved him lower in the scale of useful workers. For the rest of his life he is handicapped in the important task of earning his living.

That could not happen where a PHOTRONIC cell is used. Today these cells stand watch over such things and the giant machine is locked tightly so long as even the tip of an operator's finger is in the way of possible harm.

In the same way elevators can be levelled at floors and all sorts of machinery controlled so as to spare the people who work with them.

In this chapter we have tried to bring out the general applications of PHOTRONIC cells by showing how Weston has applied them to industry. The field of the cell is extensive indeed and is growing rapidly. It would be impossible to take up here, in detail, even its present diversified activities. If we have been able to suggest the scope and importance of photoelectric devices, then we have accomplished all that we could have hoped to do.