"Thyristor" Photoflash Units

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ABSTRACT AND INTRODUCTION

An important class of photoflash unit automatically controls exposure by regulating the duration of the flash output pulse based on measurement, with a photosensor on the unit, of the light reflected from the main subject. Such flash units are often described by their manufacturers and others as "thyristor" flash units. In modern flash units that also offer more sophisticated modes of exposure control, the more basic mode is often spoken of as the "thyristor" mode. In this article, we discuss what a thyristor is and why its name has come to suggest a kind of flash unit and a particular exposure control mode.

BACKGROUND

The thyratron

We will begin by discussing an electron device which is rarely used in photoflash systems but which is the predecessor of the device that is the focus of our discussion.

A thyratron is a gas filled electron tube used to "switch" electric current. Initially, with its *control grid* biased to a negative voltage, so long as the voltage between its cathode and anode does not exceed a certain "breakdown" level, it does not conduct.

When the control grid is driven positive, the gas begins to ionize locally, and the ionization spreads across the whole volume of the tube under the influence of the applied voltage. The result is that the tube quickly "fully conducts" in its cathode to anode path (it is sometimes said to "ignite"). The voltage drop across the tube is then relatively low and nearly independent of current. Since the current may be large (depending on the load circuit), the path from cathode to anode can be aptly spoken of as a "low resistance" path.

This conduction cannot be interrupted by reversing the grid voltage. It will only cease if and when the current through the tube drops below the *holding current* (with which there is associated a *holding voltage*).

After this happens, it is important that the voltage across the tube not rise again too quickly. If it does, the tube will reignite at a relatively low voltage owing to the fact that the ionized state of the gas does not cease immediately when the current through the tube drops to zero. It is as if we had “glowing embers” inside the tube for a little while after extinction.

A common use of the thyratron is in the control of AC motors. A synchronous timing circuit fires the tube at a preset point in the AC voltage half cycle. Thus, the motor receives voltage only for the remaining part of the half cycle. At the end of the half cycle, as the current goes to zero, the thyratron extinguishes, preventing current flow from resuming before the desired instant in the following half cycle. By changing the time in each half cycle at which the thyratron is triggered, the overall flow of energy to the motor is controlled, thus controlling its speed.[1]

The thyristor

A thyristor is a transistor-like semiconductor device that provides much the same operational mode as a thyratron. Its name in fact is an amalgam of “**thyr**atron” and “trans**istor**”. [2]

As with the thyratron, if a voltage (within the “breakdown” limit) is applied to the main path through the thyristor, there is no conduction. If a sufficient voltage is applied to the *gate* electrode, the thyristor suddenly and fully conducts, again usually with a low voltage drop fairly independent of current.

The conduction cannot be stopped by withdrawing or reversing the voltage on the gate electrode. It will only cease when the current through the device falls below a certain *holding current* (with which there is associated a *holding voltage*).

Unlike the thyratron, the thyristor will be ready to sustain a reapplied voltage without conduction very soon after extinction.

PHOTOFLASH UNITS

Basic operation

The heart of a photoflash unit is the photoflash tube, usually a glass cylinder filled with an appropriate gas (perhaps xenon) with an electrode passing through the glass wall into each end. Like a

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[1] For “full-wave” operation, we must either have separate thyristors for the two directions of current flow or a steering rectifier bridge so one thyristor will always see the same polarity. There is also a bidirectional form of the thyristor, the *triac*.

[2] Often a thyristor is called a *silicon controlled rectifier* (SCR), although to some authorities the definitions are slightly different, and so not all thyristors are SCRs.

thyratron, if the applied voltage between the electrodes is less than a certain level, there is no conduction through the gas.

When the unit is prepared for operation, a storage capacitor, to which the electrodes of the tube are permanently connected, is charged to a fairly high voltage (perhaps 120-400 V). When the unit receives the synchronizing signal from the shutter, a high-voltage pulse (generated by a small transformer) is led to a third electrode, this one usually on the outside of the tube. The very high electric field created by this pulse (the glass doesn't prevent this) locally ionizes the gas in the tube.

The ionization spreads throughout the volume of the tube under the influence of the voltage applied to the main electrodes, and the tube becomes fully conductive. A high current flows, the voltage across the tube is modest, and thus a large amount of power is dissipated in the gas. This results in the emission of light (and the creation of heat).

As the energy stored in the capacitor is consumed by the discharge, the current through the tube declines until it is less than the holding current. At that time, conduction ceases and the light output pulse ends. The duration of the pulse in a basic on-camera flash unit is perhaps 0.4 to 2 ms. In even a small unit, the peak current into the flash tube may be greater than 200 amperes (for that short time).

The capacitor is then recharged for the next operation. The rate of voltage increase is so modest that there is no danger of reignition of the tube (the phenomenon that is of concern in a thyratron).

Luminous output

This would be a good time to review how the luminous output of a photoflash unit is quantified insofar as it affects exposure. The physical property that is of most direct interest is the integral of luminous intensity (in the direction toward the subject) over time.[3] If we ignore the fact that the luminous intensity varies over the duration of the pulse (building up quickly and then dropping off more slowly), we can think of this as the product of the luminous intensity during the pulse and the duration of the pulse.

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[3] *Luminous intensity* describes luminous flux per unit solid angle of space in a particular direction from the emitter. Strictly, it only applies to a "point" source (one whose cross-sectional dimensions are infinitesimal), but can be usefully applied in the case of a source whose cross-sectional dimensions are finite so long as they are small compared to the distance at which we will be interested in the *illuminance* caused by the light.

Manual control of luminous output

The earliest small photoflash units had no provision for varying their luminous output. More sophisticated units, such as those intended for studio use, sometimes had provision for manually choosing from a repertoire of luminous output levels. This was done with one or both of the following techniques:

- Varying the capacitance of the storage capacitor by switching more or fewer discrete capacitors into a "capacitor bank".
- Varying the voltage to which the capacitor bank is charged.

Either will vary the amount of energy delivered to the flash tube during the period before it extinguished, and thus vary the amplitude and duration of the luminous output pulse.

Exposure control

With flash units of this basic class, the photographer arranged for proper exposure by choosing an appropriate aperture (f/number), taking into account the luminous output of the flash unit, the film sensitivity ("speed"), and the distance from the flash unit to the main subject.

The *guide number* system facilitated this reckoning. The guide number is a form of presentation of the luminous output of the particular flash unit. The situation for "proper exposure" is when the product of the f/number and the distance from the flash unit to the main subject is equal to the guide number. Since film sensitivity obviously enters into the equation, the guide number is adjusted to match the sensitivity of the film in use, typically using a table supplied by the flash unit manufacturer.

Often, the flash unit has an "exposure calculator (usually a small "circular slide rule") that allows the photographer, for a given film sensitivity, to determine what f/number would be appropriate for a given distance to the subject.

AUTOMATIC EXPOSURE

The principle

An important advance in photoflash technique came about with the introduction of flash units that automatically controlled their luminous output to attain proper exposure. The luminous output is controlled by controlling the duration of the output pulse by prematurely terminating the conduction of the flash tube before all the usable energy stored in the capacitor is exhausted.

The decision is made by observing the light (originating with the flash tube) reflected from the main subject, using a photodetector mounted on the flash unit itself. The indicated scene luminance is integrated over time, and when the integral reaches a predetermined level (the *cutoff level*), the flash tube is extinguished.[4]

The exposure on the film (the physical phenomenon that makes the film respond to light) is the integral of the *illuminance* on the film over time. The illuminance, in turn, is affected by the f/number of the aperture (we will ignore a few little complications) and the *luminance* of the subject. Thus, for a particular film sensitivity and aperture, proper exposure is dependent on the time integral of subject luminance

Thus if, at the flash unit, the level of the time integral of observed scene luminance at which the pulse is cut off has the proper relationship to film sensitivity and the f/number of the aperture in use, proper exposure will automatically result.

In the simplest flash unit, there is only a single cutoff level. Typically, an exposure calculator on the flash unit allows the photographer, for a given film sensitivity, to determine what unique f/number is appropriate.

In somewhat more complicated flash units, the photographer can choose from two or three different cutoff levels. Each, for a given film sensitivity, calls for a different f/number to make the process work properly, giving the photographer more control over the overall photographic process. Often, the various choices are color coded, and the exposure calculator has colored marks to allow it to be set to match for the cutoff level chosen by the photographer.

Stopping the pulse

When the time integral of observed scene luminance reaches the critical level, the light output from the flash tube must be quickly stopped. In the earliest automatic exposure flash units, this is done by triggering a second flash tube, this one sealed up in an opaque

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[4] Basically, a current flows through the photodetector that is roughly proportional to the observed luminance. That current is used to charge a small capacitor. The voltage across that capacitor becomes proportional to the time integral of the current, and thus to the time integral of the observed luminance. When that voltage reaches the *cutoff level*, the flash tube is extinguished.

chamber so its light output doesn't reach the outside world. This "quench" tube is also connected to the storage capacitor.

When the time integral of observed scene luminance reaches the cutoff level, this second flash tube is fired (using a second little high voltage transformer). It then also draws energy from the capacitor.

The voltage-current characteristic of the quench tube is such that the voltage drop across it is less than for the main flash tube. As a result, the voltage across the real flash tube almost instantaneously falls to below the value associated with the holding current, and thus the discharge in the real tube is extinguished, putting an end to its luminous output pulse. The remainder of the energy in the capacitor is consumed by the quench tube (down to the point where the current is low enough that the quench tube extinguishes). At this point, the storage capacitor is drained even further than it would have been had the main tube been allowed to conduct as long as it could.

What do we call it

Initially, this was the only scheme of automatic exposure control for flash operation that existed in general use. It was, not surprisingly, called "automatic exposure control".

Disadvantage

A great disadvantage of this system is that, even in cases requiring only a small luminous output from the flash unit (i.e., a very short pulse, as when the flash unit is close to the subject), the usable charge in the storage capacitor is more than completely spent. Thus, the time to recharge the capacitor (which has to happen before the flash unit can be used again) is always at its maximum, and the consumption of energy from the batteries (assuming a battery-operated unit) is always at its maximum. The amount of heat dissipated in the unit per cycle is also always at a maximum.

Overcoming this wasteful situation was the objective of the next advance in flash unit design.

ENERGY-SAVING UNITS

The basic design

The next generation of photoflash units avoided this wasteful consumption of the residual energy stored in the capacitor. In the initial design of this type, a thyristor is connected in series with the path from the storage capacitor to the main flash tube. It is turned on just as the tube is triggered. Thus the path to the tube is complete through the thyristor, and the tube flashes.

As before, when the time integral of the observed scene luminance reaches the appropriate critical level, the quench tube is fired. Here, the quench tube does not draw current from the storage capacitor. Rather, it is used as a switch that, by discharging a small capacitor, makes a brief but potent negative pulse that drives the voltage across the thyristor briefly negative, making the current through it fall to zero and extinguishing it. (This is sometimes colloquially described as “blowing out” the thyristor.) With the thyristor extinguished, there is no longer a path from the storage capacitor to the main tube, the main tube is extinguished, and the remaining energy in the capacitor is conserved.

Note that the current of this “blowing out” pulse must be greater than the current through the thyristor and flash tube at the time, a potentially large current.

Note that the thyristor in this case is not required to “close into a load”; when the thyristor is turned on, the load is not present (since the flash tube is not yet conductive). The load appears shortly later, when the flash tube is triggered. This eases the requirements on the performance of the thyristor.

The quench tube is a relatively costly and bulky component, and there was a quest for other implementations that could eliminate the need for it.

Thyristor quenching

Very soon, an improved design emerged. Here, when the luminous pulse is to terminated, a second thyristor is fired which, just as in the circuit described above, generates a brief “blowing out” pulse that extinguishes the main thyristor, resulting in the interruption of the path to the flash tube, extinguishing it. This advance required the development of economical thyristors that could “close into a load” of the current levels required here.

The Gate Turn Off Thyristor (GTO)

In a further improvement, the main thyristor is of a new type, the Gate Turn Off Thyristor (GTO). This device can be turned off while current is flowing through it by reversing the gate voltage. When it is time to terminate the flash pulse, the thyristor is just turned off, stopping the flow of energy from the capacitor to the flash tube, ending the pulse (and again conserving the remaining charge in the capacitor).

The Insulated Gate Bipolar Transistor (IGBT)

Most recently, flash units have been designed in which the main thyristor is replaced by a non-thyristor semiconductor device, commonly an Insulated Gate Bipolar Transistor (IGBT). This is in effect a high voltage switch that can be turned on and off at will by way of its gate voltage. It is turned on prior to the firing of the flash tube and turned off when it is time to stop the flash pulse.

This is perhaps the most common implementation in flash units today.

What do we call this?

Because it was the thyristor that (in the first implementation) made the revolutionary energy-saving flash unit possible (and because "thyristor" was such a cute name!), the manufacturers of these improved flash units often described them as "thyristor" units.

This is still common today for flash units offering "self-contained" automatic exposure control. Their circuits today may or may not actually utilize thyristors (since there are alternate semiconductor switch devices that can be used, as for example the IGBT).

OTHER METERING MODES

Today, we often find automatic exposure control systems that do not depend on measurement of the returned light from the subject with a sensor on the flash unit, but that (for example) measure that light return at the camera, "through the lens" ("TTL"). Some flash units can (at the option of the user) work either way.

How do we distinguish the modes?

Commonly, in this context, the type of automatic flash exposure control that works by measuring the return through the lens is called "TTL exposure control", and the type of automatic exposure control that works by measuring the return with a sensor at the flash unit is called "automatic exposure control". Of course, TTL exposure control is certainly just as "automatic", so this is very arbitrary. But I don't want to discourage this notation, as a widely-used alternative (mentioned next) is even less attractive.

Sometimes, authors will speak of the type of exposure control involving a sensor on the flash unit (as distinguished from TTL systems) as the "thyristor" mode.

This is not attractive. One or more thyristors may in fact be used to control the luminous pulse duration in either mode, or on the other hand there may be no thyristors involved in either mode (perhaps an IGBT instead).

CONCLUSION

We have seen that often the term “thyristor” is sometimes used to:

- Distinguish the type of flash unit that offers automatic exposure control (using a sensor on the flash unit), or

- Distinguish that mode of automatic exposure control that uses a sensor on the flash unit.

I discourage this usage. It is not apt, given that:

- Flash units offering automatic exposure control may or may not utilize a thyristor as the switching element

- Flash units offering any of the exposure control modes may employ a thyristor as the switching element

Although using “automatic” to arbitrarily indicate the mode of automatic exposure control that uses a sensor on the flash unit is not semantically ideal, it is free from the deficiencies of using “thyristor” for the purpose.

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