History

Origins of the Servo-Motor

The name "Le-Servomoteur" or slave-motor was used by Farcot in 1868 to describe hydraulic and steam engines for use in ship steering [1]. Actual origins of the term are lost in antiquity, but Otto Mayr cites a book published by the Farcot family that contains the first printed use of this term [2]. In 1896, H. Calendar in England developed the first electric servo-mechanism, which was a contactor-actuated "follow-up" device for use with strip chart recorders [3]. In 1898, Nikola Tesla experimented with "wireless control" of model ships on the Potomac River basin. He also used electric contactor "servo-motors" to steer model ships remotely. (Contactor servo is another name for time-optimal or "bang-bang" servo.) In 1908, Elmer Sperry used electric contactor "servo-motors" for his gyroscopic compasses [4]. In 1911, Henry Hobart defined servo-motor in his electrical engineering dictionary [5]. In 1916, Lawrence Sperry filed a U.S. patent application for an aerial torpedo in which a "servo-motor" moved the rudder to steer the course [4]. By 1915, the term "servo-motor" was firmly entrenched within the language of America's community of electrical engineers, and perhaps elsewhere. The term is certainly of French origin rather than English.

In 1922, work began at General Electric on "electronic Selsyn-servos" for use in directing naval guns. By 1925, GE engineers had built an electronic servo using proportional control plus rate feedback for stability, all elements of modern servomechanisms. By 1930, both GE and Westinghouse were making strip chart recorders that used electronic servo motors for driving the pen mechanism. (See note below.) By 1933, Leeds and Northrup offered a chart recorder with a DC servo, similar to the GE approach. All of these developments were empirical in nature, with little or nothing in the way of theory to support them. Minorsky's work on ship steering was the first effort to bridge the gap between practical applications and analytical or mathematical theory.

(Note: It is intriguing that the Westinghouse recorders used an AC servo with the power actuator being a modified Shallenberger induction disc. While the induction disc motor offers an elegant solution to a design problem, it was never developed further.)

The concept of the servo-motor is much older than the use of the term. The Greeks used wind-driven servo-motors to continuously adjust the heading of their windmills so the turbine blades always faced into the wind. Early history is difficult to trace because of differences in language and terms used in various quarters. The English-language terms *governor*, *regulator*, and *follow-up device* preceded the use of *servo-motor*. Many authors note that James Watt developed his fly-ball governor for regulating speed of steam engines long before the term *servo-motor* came into use.

Even today, many terms are inter-related with *servo-motor* (e.g., *servo-mechanism*, *regulator*, [*automatic*] *controller*, *feedback control*, to name a few). In modern terms, servo-mechanisms are feedback control systems incorporating servo-motors. Therefore, *servo-motor* as now used is only a component of *servo-mechanism*. It is a power actuator that drives the load. *Servo-mechanism*, *regulator*, and *feedback controller* all possess several attributes in common. The *reference input* expresses the desired value. The *controlled variable* is brought into *correspondence* with the reference input by the *actuator*. The *disturbance function* perturbs the process. A feedback means is used to evaluate the difference (or *actuating error*) between reference input and some function of the controlled variable. A servo-mechanism is usually associated with positional control.

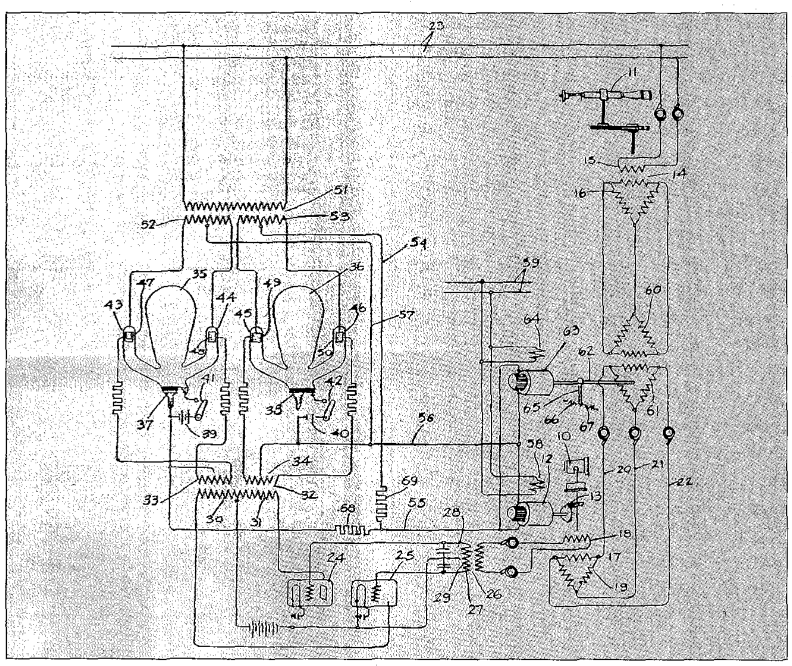

Fig. 1. DC servomechanism.

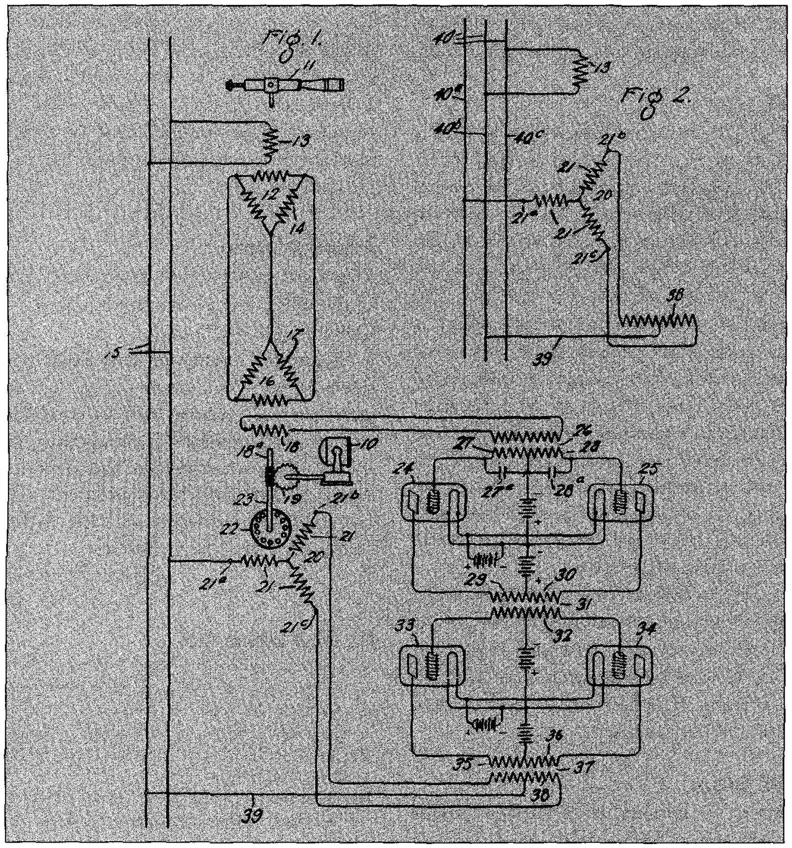

Fig. 2. AC servomechanism.

Calendar's Idea

At the turn of the century, "sensitive galvanometers" were used to detect weak electric signals. Although other types of galvanometers were also in use, the sensitive galvanometer was a deflection galvanometer similar to modern micro-ammeters. Since the needle was driven by the signal, it was incapable of developing adequate torque to drive a recording pen across chart paper. Calendar overcame this deficiency by mounting a motor-driven carriage across the width of the chart paper. The carriage supported electrical contacts (for the motor) that straddled the galvanometer needle. When the needle moved sufficiently, it closed a contact, actuating the motor and driving the carriage to correspond with the needle position. Galvanometers remained a common detector or discriminator for electric servo-mechanisms even into modern times. Other commonly used sensitive detectors utilize a torque balance arrangement with a mirror reflecting light on photocells in a bridge configuration.

Selsyn-Servos

Another widely used servo detector was the Selsyn detector. Selsyn is a registered trademark of General Electric and denotes a system of remote position indication based on rotary induction transducers [6]. (Modern induction transducers are typified by the resolver or control transformer and are two-phase equivalents of the Selsyn detector.) The Selsyn concept was patented by Joseph Michalke and assigned to Siemens Halske in several European countries prior to the turn of the century [7]. Michalke also applied for a U.S. patent in 1901. The patent was subsequently granted to Siemens Halske of America and successors in 1903. GE acquired assets of Siemens Halske of America in 1902 and thereby obtained rights to the Michalke patent when they were granted.

In 1908, Edward Hewlett was given responsibility for developing a means to remotely control the locks on the Panama Canal. The decision was finally made that the Panama Canal would be a "lock" canal rather than a sea-level canal such as the Suez. However, there was great concern for breaching the locks by misoperation. A secure means of controlling lock equipment from a central location was required to avoid the possibility that the locks might rupture. Hewlett recalled the old Michalke patent gathering dust on the shelf at GE. It was one of several candidate systems he considered for this task. Other candidate systems considered but rejected by Hewlett included step-by-step methods (stepping motor in modern terms). He selected the Michalke concept as the best means to obtain the required accuracy and reliability of measurement and set about to make a practicable device.

During this Panama Canal period, Hewlett was forming a clear concept he called *correspondence*. Although the language is now obsolete, who amongst us would not recognize "lack of correspondence" between a desired position (reference) and actual position (controlled variable) as an error (signal)? Words used by these early workers are the same words used today, but the meaning is sometimes entirely different. As an example, in 1910 when Hewlett used the word *lag* in his expression "actual position lags behind desired position," it is understood to be in the time domain. Today, the usual meaning associated with lag is in the frequency domain, as in the expression "lead-lag network." It is important to understand that the language is the same but that cultural differences exist. When reviewing works by Hewlett and others in the 1920s, the reader should understand that the meaning of some terms has evolved over the years.

By this time, GE established a close relationship with the U.S. Department of the Navy that has continued to the present time. During the Spanish-American war, the Ward-Leonard system of turret turning was a demonstrated success [8]. The subsequent success of the Panama Canal lock equipment added further to the relationship.

The outbreak of World War I focused attention once more on the need to direct guns more rapidly and precisely. In response to these and other urgent needs, the U.S. Navy established a Naval Consulting Board to provide themselves with "science-based technology cultivated by specialists." The board was chaired by Thomas Edison and brought together the best talents from industry to assist in the war effort. It included such notables as Frank Sprague and Benjamin Lamme (Westinghouse), representing the AIEE; Peter Cooper Hewitt and Thomas Robins, representing the Inventors Guild, Elmer Sperry, Willis Whitney (GE), and John Hays Hammond. The Board provided a forum for free exchange of ideas, including the latest on servos and positioning controls. It was also plagued by bottlenecks brought on by the strong stance taken by Thomas Edison on several matters, particularly the circumstances surrounding the Naval Research and Development Laboratory.

In May 1922, the Navy came to Schenectady to enlist the support of Ernst Alexanderson and his team of scientists and engineers to improve on the power and accuracy then available from the Selsyn technique for control of guns [9]. Alexanderson's team included Edward Hewlett, Al Mittag, Sam Nixdorff, W. Willard, and others. The team worked on the problem for several months, during which time several varieties of electronic servo-mechanisms were developed. Edward Hewlett led the effort to develop an improved means of determining correspondence. Electronic tubes were available for amplification of weak signals. The Pliotron (high vacuum) tube had been available for several years, while the Thyratron (gas discharge) tube was only recently available [10].

It was a time of extremely rapid progress, with radical improvements occurring almost weekly. To illustrate, the means of determining correspondence took a complete reversal from the earlier ideas of Hewlett into a form we recognize today as a "null" detection approach characteristic of Selsyn-servos. The change in thinking is the intellectual equivalent of the reversal that occurs when making a photographic positive print from a negative image. The old ideas of Hewlett required the use of three "sensitive" detectors, one in each phase of the Selsyn stator connections. The new idea required only one null detector (phase discriminated) in the single-phase rotor connection. The resulting system was much simpler and more reliable. The old ideas were intellectually less efficient and therefore did not survive the 1920s.

DC Servos

Fig. 1 is extracted from the U.S. patent disclosure of Mittag filed in 1925 [11]. The telescope is geared to the transmitting Selsyn (devices 11 and 14), providing reference information to the receiving Selsyn that is geared to the search light (devices 17 and 10). The error signal from the receiving Selsyn is proportional to position error, hence proportional feedback signal. A differential Selsyn (device 60) is inserted between transmitter and receiver to modify the error signal. A torque motor (device 63) acts on mechanical spring (devices 66 and 67) to introduce a signal proportional to rate (servo speed), hence proportional plus rate feedback.

The servo motor is a shunt field DC motor with armature supply from phase controlled mercury arc rectifiers (devices 12, 35, and 36). This would be called an electronic Ward-Leonard system, if not static Ward-Leonard.

AC Servos

Fig. 2 is extracted from the U.S. patent disclosure of Mittag filed in 1923 [12]. The reference is again provided by telescope geared to the transmitting Selsyn (devices 11 and 12) and providing reference information to the receiving Selsyn that is geared to the search light (devices 20 and 10). The error signal from the receiving Selsyn is proportional to position error, hence proportional feedback signal. Stability is provided by phase shift obtained by adding capacitors (devices 27 and 28). The servo motor is a squirrel-cage induction motor with constant main-axis excitation and proportional cross-axis control. This may be the first AC servo ever developed.

Subsequent Developments

The modern era of automatic control began around 1930. Development by trial and error typified the early period described above. This empirical approach was superseded by a newer scientific approach based on building control systems from elementary components, the characteristics of which are well known. The mathematics became available to permit design by analysis and synthesis. World War II stimulated rapid development of servomechanisms to train guns and other implements of war.

Acknowledgment

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The author wishes to acknowledge considerable help from many persons but in particular Hal Chestnut and C. Concordia. Any errors or omissions lie strictly with the author. There are many fascinating stories associated with the fields of automatic control, regulators and servo-mechanisms, this being only a very brief summary.

—Edward L. Owen

For More Information

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