THE TWENTY-FIRST IEEE CEMENT INDUSTRY TECHNICAL CONFERENCE

May 21-24, 1979

FOREWORD

THE TWENTY-FIRST IEEE CEMENT INDUSTRY TECHNICAL CONFERENCE

May 21-24, 1979
INNISBROOK RESORTS, TARPON SPRINGS, FLORIDA

Sponsored by
THE CEMENT INDUSTRY COMMITTEE
PROCESS INDUSTRIES DEPARTMENT,
INDUSTRY APPLICATIONS SOCIETY
OF THE
INSTITUTE OF ELECTRICAL AND ELECTRONIC ENGINEERS, INC.

The technical papers in this Conference Record have been prepared using guidelines from the "Author's Guide" of the Industry Applications Society (IAS) and modified by the Cement Industry Committee. The Committee is one of twenty-eight Technical Committees within the IAS.

This Twenty-first Annual IEEE Cement Industry Technical Conference completes twenty-one years of such Conferences. The number of registrants at these Cement Conferences started at 298 in 1959 and has now grown to often be in the 600-700 figure with many wives also attending.

The papers included in this Record were written and are presented to comply with the scope for the Cement Industry Committee which has been established by the IEEE Industry Applications Society. In substance, this scope is:

> "— The development and application of electrical systems, apparatus, devices, and controls to the processes and equipment for which the emphases or dominant factors specifically relate to the cement manufacturing industry; the promotion of safe, reliable, and economic installations; the encouragement of energy conservation; and the creation of voluntary engineering standards and recommended practices".

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As of spring 1979 the Cement Industry Committee is organized to include:

— Fifty-three members plus:

- Eight additional members serving only on the West Coast Subcommittee.
- Members of the 1979-82 Conference Committees.

— Six operating Working Groups:

- Automation
- Drives and Related Products
- General Practices
- Power Generation and Distribution
- Maintenance and Safety
- West Coast Subcommittee

— Seven staff Working Groups or Subcommittees:

- Awards and Recognition
- Bylaws and History
- Conference Site Selection
- Executive Subcommittee
- IEEE Relations
- Nominating Subcommittee
- Papers Review

— Five liaison representatives to:

- ANSI Activities Committee of the IAS Standards Department
- Energy Committee of the IAS
- Mining Safety Standards Committee of the IAS Standards Department
- Safety Committee of the IAS Standards Department
- Standards Projects Committee of the IAS Standards Department

It is hoped that these technical papers will assist in increasing the understanding and professional stature of all those who prepared them and who read them. Gratitude is expressed to the dedicated work of supporting the activities of the Institute (IEEE) by many Çement Industry Committee members who have given countless hours in discharging their roles as Committee members. Gratitude is also expressed to the many cement manufacturers, to their employees, to those who supply electric equipment and services to them, and to all who attend this Conference for their participation in the activities of this Twenty-First IEEE Cement Technical Conference.

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SUMMARY OF ANNUAL CEMENT CONFERENCES

No.	When	Where	Chairman: Cement Committee	Chairman: Program Committee	Approx. No. of Registrants	Co-Sponsored By Local IEEE Section?	Banquet Speaker
1st	4/15-16/59	Allentown	W.A. Allen	A.H. Huelsman	298	Yes	C.S. Crawford, Pres. Whitehall Cement
2nd	5/17-19/60	Milwaukee	W.A. Allen	V.G. Murdock	316	Yes	C.C. Van Zandt, Ex-VP, Lone Star Cement
3rd	4/18-20/61	Detroit	J.F. Hower	L.E. Swanson	307	Yes	C.B. Baker, Pres. Universal Atlas Cement
4th	4/3-5/62	St. Louis	J.F. Hower	J.B. Woodward	437	Yes	W.J. Young, VP, Lehigh Portland Cement
5th	4/23-25/63	Cleveland	R.J. Jager	G.E. MacDonald	304	Yes	R.P. Schemm, Pres. Huron Portland Cement
6th	4/14-17/64	Pasadena	R.J. Jager	D.B. Carson	433	Yes	J.H. Mathis, Pres. Lone Star Cement
7th	5/11-13/65	Allentown	H.P. Cassel	C.A. Zimmerman	601	Yes	G.E. Warren, Chmn. Bd., Southwestern Pt. Cement
8th	5/17-19/66	Denver	H.P. Cassel	W.A. Walkling	436	No	Cris Dobbins, Pres. Ideal Cement
9th	5/16-19/67	Albany, NY	L.E. Swanson	J.R. Kelley	470	Yes	N.L. Moylan, Public Relations, State of NY
10th	5/20-24/68	St. Louis	L.E. Swanson	A.C. Lordi	515	No	R.B. Martin, Pres. Dundee Cement
11th	5/13-15/69	Toronto	A.C. Lordi	J.A. Allan	501	No	J.T. Kennedy, Pres. Canada Cement
12th	5/12-14/70	Indianapolis	A.C. Lordi	G.F. Messinger	453	No	John Kringel, Pres. Lone Star Cement
13th	5/10-13/71	Seattle	J.A. Allan	F.J. Bauer	370	No	M.R. Shilling, Pres. Ideal Basic Industries
14th	5/16-18/72	Detroit	J.A. Allan	L.E. Swanson	464	Yes	R.S. Chase, VP Sales, Dundee Cement
15th	4/30-5/3/73	Miami	R.P. Kistler	L.W. Copple	503	Yes	R.L. Browning, Ex-VP, Lehigh Portland Cement
16th	5/13-16/74	Mexico City	R.P. Kistler	R.J. Plass	676	Yes	Bernardo Quintana, Chmn. of Bd., Cementos Tolteca
17th	5/5-8/75	Montreal	F.J. Bauer	M.S. Jackson	583	Yes	R. Boyd, Pres. James Bay Energy Corp.
18th	5/17-20/76	Tucson	F.J. Bauer	J.A. Vidergar	587	No	R.H. Castro, Gov. State of Arizona
19th	5/16-19/77	Omaha	R.C. White	F.E. Staples/R.F. Palmer	570	Yes	R.L. Hruska, US Senator, State of Nebraska
20th	5/15-18/78	Roanoke	R.C. White	K.C. Wiles	576	No	Ty Boyd, Professional Speaker
21st	5/20-24/79	Tarpon Spr., FL.		F.W. Cohrs			
22nd	5/20-22/80	Toronto		M.E. Wrinkle			
23rd	5/3-7/81	Birmingham		W.E. Ellis			
24th	May '82	Vancouver		A.C. Lordi*			
25th	May '83	Allentown					

*Responsible for making preliminary arrangements.

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ANALYSIS OF FEEDBACK EQUIPMENT AS RELATED TO DRIVE SYSTEMS

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ABSTRACT

This paper describes feedback devices and components associated with electrical adjustable speed drives used primarily in the cement industry. Emphasis is on devices sensing the directly controlled variables of acceleration (torque), speed, and position and not process variables such as temperature, pressure, flow, etc. Some typical circuit schemes are also included.

INTRODUCTION

As cement industry processes become more complex and sophisticated, adjustable speed drives are being used to control more of the process variables. In fact, not too many years ago very few adjustable speed drives could be found in a cement plant. Constant speed fans were damper controlled, constant speed pumps were throttled and feeders had slide gates or were manually adjusted with simple mechanical speed changers.

Now with the use of high performance electrical adjustable speed drives which must contend with electronic interface, noise, ground loops, and severe environments, these drives require very stable and reliable components for expected process control.

This paper describes various feedback devices and directly related circuits and schemes used in the cement industry along with basic feedback philosophy. Elements of drive system design, stability, etc. are not included. In addition, feedback devices used in outer process loops to measure pressure, flow rate, weight, temperature, etc., are also beyond the scope of this paper.

WHAT IS FEEDBACK

"Feedback is that property of a closed loop system which permits the output (or some other controlled variable of the system) to be compared with the input to the system (or an input to some other internally situated component or sub-system of the system) so that the appropriate control action may be formed as some function of the output and input. More generally, feedback is said to exist in a system when a closed sequence of cause and effect relations exists between system variables." [1]

This definition is of course quite general and must be narrowed down to be meaningful in our context. Feedback in adjustable speed drive systems usually consists of sensing the direct controlled variable; that is, the variable directly related to the adjustable speed drive shaft. It could be thought of as the variable the drive regulator and drive itself can control directly.

The usual drive directly controlled variables are essentially based on the fundamental laws of motion which are the variables acceleration, velocity, and position. According to Newton's second law of motion, the summation of all forces on a body is equal to its mass times acceleration. In rotational motion, this same statement can be made that the summation of all torques on a rotational system is equal to its rotational moment of inertia times its angular rate of acceleration.

As an example, suppose that the motoring torque of a drive exactly equals the applied load torque. The summation of torques would then be equal and opposite in sign so that the resultant acceleration would be zero. Reasoning further then since the rotating moment of enertia (commonly designated WK^2 or WR^2) is constant which is generally the case, by using drive torque as the directly controlled variable, the mechanical system acceleration rate can therefore be controlled.

If the acceleration rate of a drive system is non zero for any length of time, a change in system velocity (or commonly speed) will result. Quantitatively, the velocity of a system is the time integral of its acceleration. Thus, we can have velocity or speed as a directly controlled variable.

To continue, if the velocity of a drive system is non zero for any length of time, a change in system rotational shaft position will result. Again quantitatively, the position of a system is the time integral of its velocity. Similarly we can have shaft position as a directly controlled variable. These relationships are shown in Figure 1.

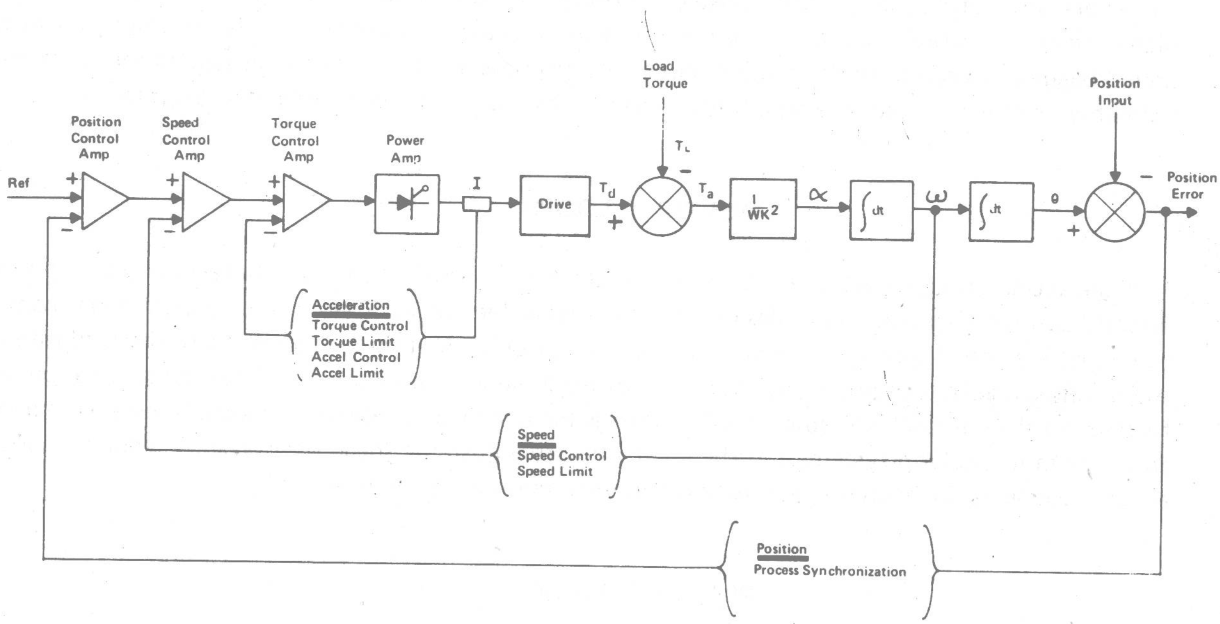

Figure 1 Basic Drive Feedback Relationships

PRACTICAL APPLICATIONS

Torque or acceleration control is not too common in the cement industry but some examples would be accelerating long horizontal belt conveyors up to speed or accelerating high enertia fans. Torque control can be utilized where the drive is required to develop a controlled output torque independent of its output speed or position. This implies that the drive is rigidly connected to a large mechanical system which is relatively unaffected by the torque of the drive in question. While perhaps not seen in the cement industry, these applications are winders, unwinders, and helpers in web handling processes, towing and mooring winches, etc.

By far the most common controlled variable used on drives in the cement industry is velocity or speed. It is almost directly related to process variables such as material weight or volumetric flow rate used in conveyors and feeders, gas or air flow rates used in fans and blowers, and fluid flow rates used in both centrifugal and positive displacement pumps.

The remaining directly controlled variable is position. These drive systems usually appear not singly but in two or more separate mechanical systems which must be synchronized in order to, perhaps, pass an item from one system to another at a predetermined position or slot. Systems of this sort are automotive assembly conveyors, component assembly operations, can and bottle filling lines which of course are not seen in the cement industry. However, since position systems are common in synchronized assembly operations, they could possibly appear at some future time in, for example, an automated bagging operation in the cement industry. Anytime a material handling system for finite and definable units is involved, the possibility exists for the use of a synchronized drive system.

MULTIPLE LOOPS

While acceleration, velocity, and position are directly controlled variables in feedback systems, indirectly controlled process variables can also be used as feedback. There can be weigh feeder controls to maintain a preset tons per hour output, compactor or briqueting machines where the feed rate to the machine and output quality is a function of machine load as examples. Extending this approach further, all the feedback variables in kiln controls for instance are feedback loops. In essence, however, these are multiple loop systems and the inner primary adjustable speed drive system feedback loops are still acceleration, velocity, or position and most commonly velocity.

WHY FEEDBACK

The most important characteristics the presence of feedback imparts to a system are the following: [1]

1. Increased accuracy. For example the ability to faithfully reproduce the input.
2. Reduced sensitivity of the ratio of output to input to variations in system characteristics.
3. Reduced effects of non-linearities and distortion.
4. Increased band width. The band width of a system is that range of frequencies (of the input) over which the system will respond satisfactorily.
5. Tendency toward oscillation or instability.

The first four above items are benefits of feedback and include the use of the devices to be described. The last item is a disadvantage and is the price one pays for the benefits of the first four. Obviously then, some sacrifice must be made in the first four items to obtain a stable and well behaved drive system.

To achieve satisfactory performance in all five of the above characteristics, a drive system will most likely include more feedback loops and devices in a particular system than the directly controlled variable loop using the devices described in this paper. For example, a DC system having speed or tach feedback as the direct controlled variable will also have inner control loops with both armature voltage and current feedback. A static adjustable frequency system, while often appearing open loop without tach feedback, will have both DC bus voltage and current feedback to achieve proper performance. An eddy-current system having tach feedback will also have coil current feedback. In addition, both the DC motor and AC induction motors themselves have an inherent inner speed loop caused by the counter EMF in the motor itself. An AC synchronous motor even has a position loop internal to the motor itself.

It should, therefore, be emphasized that inner loops (such as current, voltage, acceleration, velocity, etc., in drive systems are either inherent or may be included to obtain specified performance and stability and generally are not considered the direct controlled variable in this paper.

TYPES OF FEEDBACK DEVICES

Torque (acceleration)

In almost all electrical drive systems, a measure of electrical current in some portion of the power system will provide indication of shaft torque. Actually the measured current is closer to air gap torque rather than actual shaft torque but in most applications the difference is of minor consequence. Only in extreme high response drive systems involving rapid speed changes will the air gap torque be appreciably different than the shaft torque because of rotor inertia and some possible rotor time lags.

AC current transformer. The AC current transformer is generally a two winding transformer providing a secondary output AC signal in a fixed ratio proportional to the AC current passing through its primary winding. In general, it can be considered as the usual potential transformer but with its secondary shorted by a very low impedance. This is a very common device and considerable literature exists so details will not be covered in this paper. [2] The transformer is, however, designed for sinusoidal current wave shapes so that accuracy on controlled rectifier power systems can be a problem. In most drive systems, the transformer output signal is rectified and filtered to obtain a DC analog signal to use in the adjustable speed drive control system. Filtering will cause additional time lags which must be considered to maintain system stability. Some more complex circuits utilize the peak value of AC current to minimize the time lag and also to compensate for the non-sinusoidal wave shape.

DC Shunt. A shunt is a stable calibrated resistor of a very low resistance value through which current, generally DC, passes. The voltage developed across this resistor is then a measure of the instantaneous value of the DC current. This device is quite simple but does not provide electrical isolation between high level power circuits and low level logic circuits.

DC current transformer. Several methods are available to obtain a measure of DC current and retain the advantage of circuit isolation as in the AC current transformer. One method is to have the DC current pass through a control winding of a self-saturable reactor. The output of the reactor then is proportional to the DC current within the linearity and accuracy limits of the self-saturable reactor circuitry. Another method to obtain circuit isolation is to amplitude modulate an AC chopper carrier system, typically about 3 kilohertz, with the DC current signal perhaps obtained as a voltage across a DC shunt. The modulated carrier is then put through an isolation transformer and then de-modulated to obtain a signal proportional to the original DC current.

Shaft strain gauge. In controlling torque of an adjustable speed drive, it would be most desirable to sense the very controlled variable itself, namely, shaft torque. All previous methods of providing torque feedback were in a sense somewhat indirect. While usually rather expensive and not used appreciably in the cement industry, shaft torque strain gauges are available and along with the necessary electronics, a signal can be obtained which is proportional to shaft torque with very high accuracy.

Speed.

Drive shaft speed is probably the most common directly controlled variable used in the cement industry (and in most other industries also) because so many operating process variables are so directly related to drive speed. A great many types and methods of tachometer (speed) feedback are available.

AC tachometer generator. This device is essentially a permanent magnet single phase synchronous generator, from 24 to 36 poles, with an output of from 50 to 80 volts AC RMS at top drive speed. They are available in one form or another from almost all drive manufacturers. Normally, the output is simply rectified and filtered to obtain a DC voltage proportional to drive speed for analog feedback into the regulator electronics. Usual drive performance specifications with this tachometer are up to 0.5% of top speed regulation with load change and perhaps 2% of top speed caused by drift, linearity, etc. Speed range is also normally limited because tachometer generator ripple frequency and its rectifier and filter approach the natural drive system frequency at low speeds. Low speed operation may further be restricted by a rectifier voltage drop and also if the tach generator and electronics are connected through an isolation transformer. However, this isolation can be an advantage if the generator signal is also required in other electronic networks or if electrical noise is a problem. AC generators are available in very rugged and serviceable enclosures.

DC tachometer generator. This device is a precision DC generator with armature, commutator, brushes, and permanent magnet field. They can be made to have very low drift characteristics with a very high degree of linearity. Drive system performance using DC tach generators can approach 0.1% of top speed regulation with load change and possibly 0.2% of top speed with drift, linearity, etc. The generator must however operate at almost no electrical load. Speed range can be very wide because ripple and filter losses and lags are generally at a minimum. Because the generator analog voltage is connected directly into the drive electronics, DC isolation is not possible without added circuitry.

Digital sensors. Digital pickups provide an electrical AC signal which is proportional to the drive shaft speed. Since only the frequency of the signal is used, any variations in pulse shape, peak voltage, RMS voltage, average voltage, etc., caused by temperature variations, aging, etc., have no effect on signal accuracy in a properly designed circuit. The only relevance is whether a pulse is present or not. The conversion of the frequency information to drive system control logic is accomplished inside the closely controlled environment of the drive system electronic cabinet. As a result, drive system accuracies can be improved over the long used and familiar DC tach generator feedback systems. Some types of digital sensors and pickups are as follows.

1. **Magnetic Pickup.** This device essentially consists of a coil, pole piece, and magnet all mounted, usually in a tubular housing. When the pole piece is placed close to the teeth of a rotating gear of magnetic material (approximately 0.005" clearance), an AC voltage is generated in the coil whose frequency is proportional to the number of teeth passing the pole piece per unit of time. While the AC voltage is also proportional to gear speed, it is the frequency information that is used. A minimum gear speed is required below which no output is obtained. This feature can be a problem in some applications. The magnetic pickup with this associated gear is usually mounted in some type of an enclosure for proper environmental protection.

2. **AC Tachometer Generator.** This generator, previously discussed for simple analog systems, can also be used in digital systems similar to the magnetic pickup by using the frequency information of its AC output voltage. This can be very convenient since the AC tach generator is either included as standard or is a very low cost addition to most adjustable speed drives.

3. **Zero Velocity Pickup.** This is an active device requiring low level electrical power and is similar in appearance to the magnetic pickup. However, rather than requiring motion of the gear teeth past the sensing head, the zero velocity pickup senses merely the presence or absence of a gear tooth to change its output state. Thus, the electrical output pulses are nearly constant voltage level regardless of frequency and with output down to zero speed.

TYPICAL SPEED CONTROL CIRCUITS

Analog

AC and DC tachometer generators are primarily used in analog regulating systems in which the tachometer output is a voltage proportional to drive shaft speed. This voltage is fed into usually an operational amplifier summing network along with the speed reference and other drive regulator system internal loop stabilizing voltages.

Digital (Frequency to Analog Converter)

Digital feedback systems using digital pickups or AC tachometer generators generally use circuits of two types. One type is a frequency to analog converter with a very high accuracy and drift specification and special added features tailored for adjustable speed drive regulating systems. (Figure 2). The circuit, with a very accurate speed reference, provides an error integrating speed trim signal to a standard performance adjustable speed drive. A very precise and stable analog velocity feedback signal is derived from a standard AC tach generator or digital pulse pickup by means of a precision frequency to voltage converter circuit. The negative feedback signal is then summed with the speed reference signal to obtain an error signal. The integral of the error signal is summed with the speed reference signal and used as the speed reference for the drive.

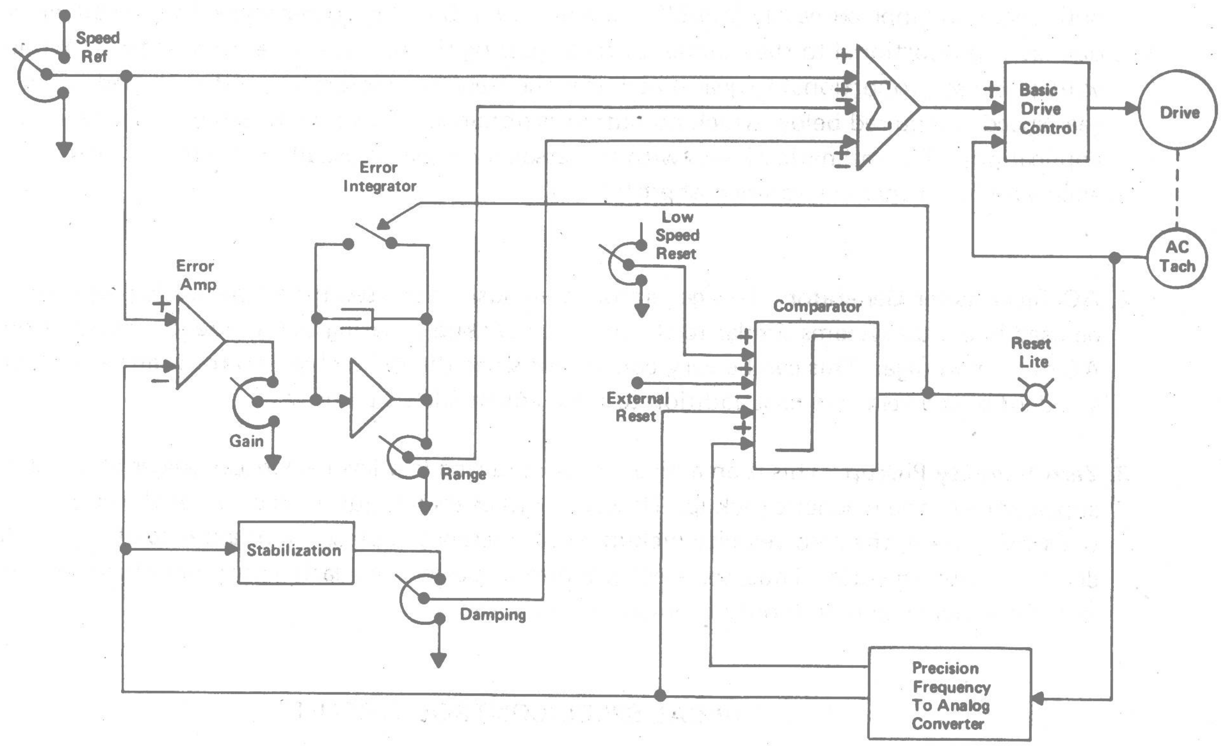

Figure 2 Frequency to Analog System

Since the integral of speed error is used as the speed trimming signal, the long term speed regulation accuracy is limited only by the stability of the speed reference signal and the accuracy and stability of the speed feedback and error measuring circuits. The key feature of the circuit is the use of a crystal oscillator to convert the pulses from the digital or AC tach generator to pulses of precisely uniform height and width so that the frequency to voltage conversion can be accomplished very precisely. The accuracy and stability of the frequency to voltage converter and the error measuring circuits is assured by the use of high quality components in standard circuit designs.

Dynamic performance, transient speed regulation under conditions of step changes in load, are largely determined by drive and load parameters but the speed and gain of the trim circuit are also important factors. The speed of the frequency to voltage converter is determined by the number of pulses per revolution of the pulse tach pickup and by the ratio of the pulse width to frequency used in the pulse standardization circuit. The acceptable level of circuit gain is determined by system stability. The regulator circuit may include an input for a stabilization signal which can be obtained from the drive system.

A circuit is provided to reset the integrator at a preset low operating speed and allow the drive to operate below this point without trim since the frequency to voltage converter has a minimum frequency limit. The integrator is also reset at overspeed conditions. An input terminal can be provided to allow the integrator to be reset externally and indication can also be provided when the integrator is reset. Total accuracies of 0.1% and better of top speed are available from circuits of this type.

Phase Lock Loop

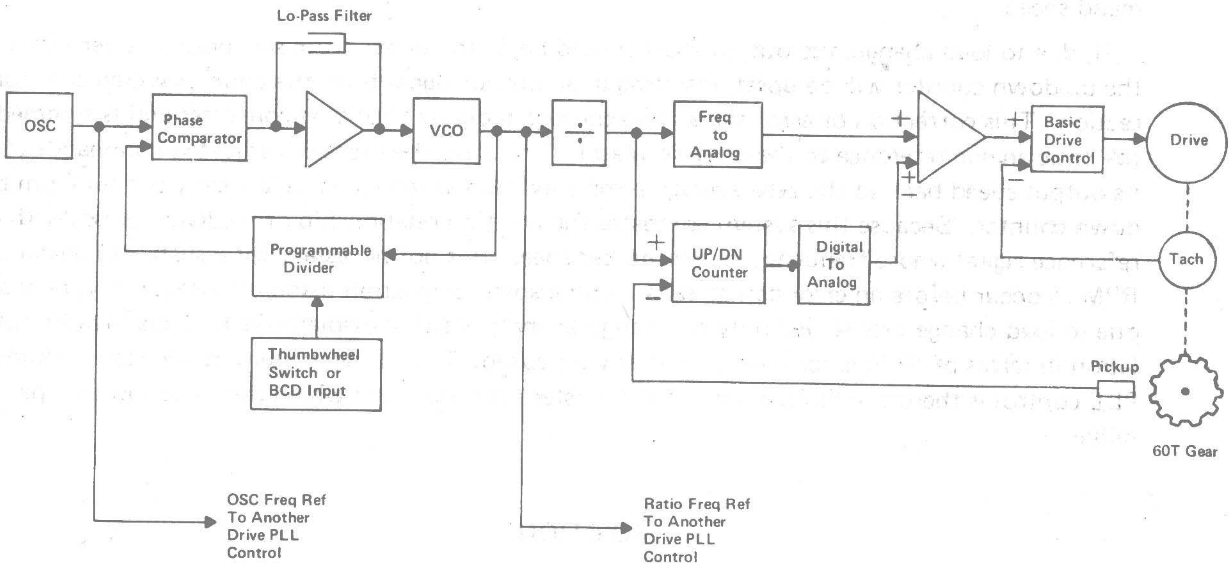

Figure 3 Phase Lock Loop System

Another type of digital feedback system utilizes a phase lock loop (PLL) to achieve extremely high accuracies. (Figure 3) The fundamentals of PLL theory are adequately described in the literature [3] but essentially the heart of the overall drive regulating system is a highly accurate crystal controlled oscillator. This single oscillator provides the digital reference signal for as many drives as the system may encompass. The master frequency is digitally divided down to other frequencies (which represent speed command signals to the drive) using PLL techniques. This assures that the absolute accuracy of the crystal oscillator source is not lost in the digital frequency division process. The divisor (and thus the desired speed) is normally manually entered into the system by a three or four-decade thumbwheel switch bank having a binary coded decimal output. The use of these BCD commands permits settability in exact increments of speed (0.1% or 0.01% of maximum RPM) and also provides for exact repeatability of any predetermined setting for a particular process. In process control applications, the system can easily accept BCD speed command signals from a computer in lieu of the manual BCD switches. After passing through the phase lock divider, the reference signal feeds into a frequency to voltage converter and becomes an analog speed reference signal to the drive regulator. This reference is compared with analog speed feedback from a tachometer generator in the drive to establish a basic coarse inner loop of speed control.

At the same time, the PLL outer loop, which achieves zero average speed error, is accomplished by feeding the reference frequency, still in digital form, into the plus input of an up-down counter. The minus input of the same up-down counter receives digital speed feedback information from a digital pickup mounted on the drive shaft. When the drive is running at exactly the speed commanded, each pulse going into the plus side of the up-down counter from the reference will be cancelled out by a pulse at the exact same frequency coming into the minus side of the up-down counter from the digital pickup. The residual total of stored pulses in the counter will be zero and thus the output of the counter will be zero meaning that no correction signal is being issued, since the drive is running at its command speed.

If, due to load change, the output shaft should begin to deviate from set speed, the zero balance in the up-down counter will be upset, resulting in an output signal from the counter which calls for a correction. This correction or error signal goes through a digital to analog converter and is summed with the basic analog reference to the drive regulator. The drive then receives adjusted commands to correct its output speed back to the zero average error condition as indicated by a steady output from the up-down counter. Because this system compares the position relationship of feedback pulses with a digital reference signal whose frequency represents set speed, it is not necessary for a sustained deviation in RPM to occur before an error can be sensed and a speed correction made. Consequently, regulation due to load change is observed only as an angular shaft position displacement. Thus, steady state regulation in terms of RPM is zero per cent at any set speed. Total drive system steady state accuracy with PLL control is therefore limited only to the master oscillator drift which can be as low as 3 parts per million.

POSITION

The types of devices used in drive systems for position feedback are quite varied. However, one common feature of almost all of them is that they are usually not directly attached to the drive shaft as is a speed feedback device, but are driven from or mechanically connected to the process or material itself.

Position feedback is very common in some industries but not in the cement industry, so only a very brief listing of some of the most commonly used devices will be described.

Synchro

These devices are similar to a fractional horsepower motor in appearance and have a three phase stator and a single phase rotor with the rotor connected to slip rings. The devices are mechanically connected to the processes being synchronized. With the three-lead stators of two devices connected together, single phase AC voltage is applied to one rotor (generator). The phase relationship of voltage output of the other rotor (control transformer) is then compared to the reference (generator) voltage through various types of electronic demodulator circuits and the shaft position of the control transformer is then determined relative to the generator shaft. The demodulator output signal is then applied to the drive system positioning the control transformer to maintain the control transformer shaft within a predetermined position error with respect to the generator shaft.

Linear variable differential transformer

This device (LVDT) consists of a primary and two secondary coils symetrically wound in the form of a hollow cylinder. A magnetic iron core supported by a rod is connected to the process to sense displacement. With the primary coil connected to an AC supply, the voltage output of the two secondary coils will either be in phase, out of phase, or at a null condition. The phase and magnitude voltages, determined by the core axial position with respect to the null point, are demodulated and used in the drive system similar to the syncro.

Potentiometer

A linear or rotary potentiometer is a very common device used as position feedback. With the potentiometer shaft connected to the process, the voltage output from the wiper arm with respect to one end is an accurate signal of shaft position when compared to the total supply voltage across the potentiometer.

Absolute shaft encoder

This is usually a small rotating device with an internal shaft mounted disk. The disk is divided up into equal sectors alternately opaque and clear through which light to a sensor either passes or is blocked depending on shaft position. A number of binary digital channels, each with its own set of sectors, can be used, the more channels the smaller increments of one revolution can be sensed. Thus only one binary number describes the smallest sector. Other channels may be used for direction sensing as well. The binary signal is then decoded and the resulting position signal can be used in the drive control system for proper control action.

CONCLUSION

With more and more adjustable speed drive systems finding use in the cement industry, selection of the proper feedback device to measure the directly controlled variable and provide specified drive performance is most important. This paper has described many types of devices available in the marketplace and with proper analysis a suitable feedback device can be selected for the application. Since the device must meet both the user's and the drive supplier's requirements, both parties must closely coordinate their efforts in the selection.