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CONFERENCE RECORD OF 1991 FORTY-THIRD ANNUAL CONFERENCE OF ELECTRICAL ENGINEERING PROBLEMS IN THE RUBBER AND PLASTICS INDUSTRIES

April 15 & 16, 1991

Sponsored by the

Rubber and Plastics Industries Committee
of the IEEE Industry Applications Society
and the IEEE Akron Section

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Papers presented at the Forty-Third Annual Conference
Akron, Ohio
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A HIGH EFFICIENCY-LARGE HORSEPOWER VSD FOR A BANBURY MIXER

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SUMMARY

Various types of electric variable speed motor drives are available for variable torque loads, typically pumps and fans. Constant torque loads present a more arduous duty to the drive. This paper covers the concept of the variable speed synchronous motor drive. An example of a 2000 HP Banbury Mixer drive is then presented.

INTRODUCTION

Different methods have been used to drive Banbury Mixers. We are going to focus on electric variable speed control. Both DC and AC drives have been used to achieve this control. Banbury Mixers present certain challenges to the drive mechanism and especially to variable speed controllers. This type of load is referred to as a constant torque load. While it does present many characteristics of constant torque, including high starting torque (perhaps 1.5-2.0 per unit), and the ability to require full load torque anywhere in the speed range, the actual load torque required during a mixing cycle is anything but constant. The drive equipment will typically see rapid torque fluctuations that can go from nearly no load to greater than full load.

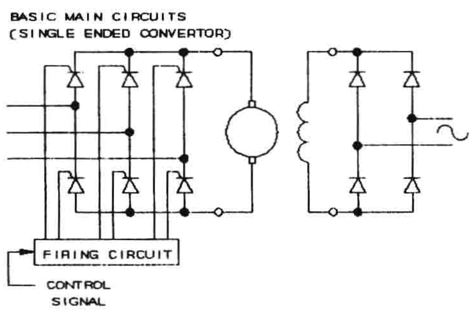

FIGURE 1

DC drives have been commonly used for this application. (See Fig.1)

The advantages of the DC drive system are:

1. Wide speed range.
2. Constant torque from zero speed to base speed.
3. Small power converter.
4. Simple power circuit and regulator.

The disadvantages of the DC drive system are:

1. Motor brushes.
2. Motor feedback device required to achieve required regulation.

AC drives, using induction motors, can also be used for a Banbury Mixer, however their use is less common than the DC drive. (See Fig.2)

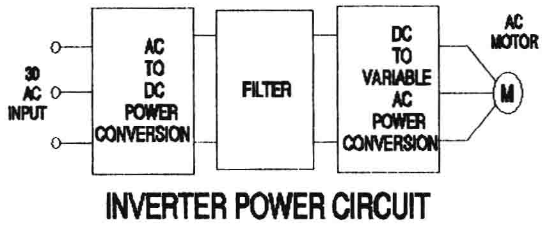

FIGURE 2

The advantages of this type of AC drive are:

1. The induction motor is a simple, reliable machine that is readily available. Some suppliers have them in stock up to 500 HP.
2. Some of the power converters are built to maintain a constant input power factor throughout the speed range.

The disadvantages of the AC drive system are:

1. Some AC Drive types are not capable of constant torque operation.
2. Some of the types that are capable of constant torque, such as a vector control drive, require a feedback device that complicates the induction motor.
3. Most of the AC induction motor drives that are available are limited to 1000HP or less.
4. Some require extra circuits to turn off the thyristors.

This then shows that there is an opening for another variable speed drive, if it could produce high power levels, do it reliably, have high efficiency, plus maintain the advantages previously described while removing the disadvantages. This need is filled by the variable speed synchronous motor drive which is referred to as a Load Commutated Inverter or LCI.

OPERATION

The synchronous motor drive consists of two SCR,(Silicon Controlled Rectifier), bridges in series feeding the synchronous motor. (See Fig. 3)

The input or supply side bridge is called the supply convertor and the output or machine side bridge is called the machine convertor. The supply convertor operates as a phase controlled rectifier to convert three phase AC input power to variable DC which is the input to the DC link. The machine convertor directs the controlled DC power and converts it into three phase AC by switching into the correct phases

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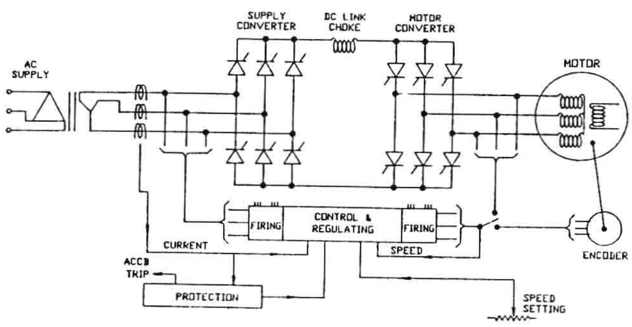


FIGURE 3

of the motor at the proper time. The motor has a field winding which is controlled by a separate power controller. In this manner the system can be thought of just as a DC drive where the brushes and commutator are replaced by an SCR bridge, (the machine convertor). (See Fig. 4)

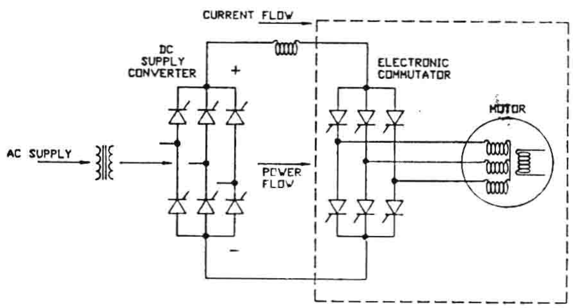


Figure 4

The supply bridge controls the power to the motor and thus the motor speed. The machine convertor switches the power appropriately to the motor, as directed by the motor speed. (See Fig. 3)

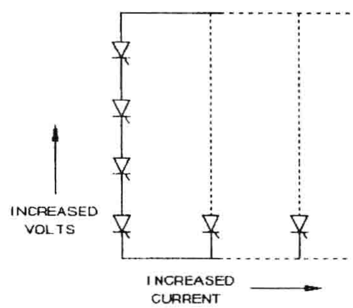
This is an important point and is a significant difference between an LCI drive and induction motor drives. In the induction drive the convertor forces a frequency onto the motor and the motor reacts to the new frequency and if the torque required to respond to the new frequency command is within the capability of the motor and convertor the motor will go to the new speed.

With the LCI, the speed of the motor is adjusted by changing the power in the DC link. If the torque required by the load is within the capability of the motor and convertor the motor goes to the new speed requested. Only by this change in motor speed is the firing rate, (frequency), of the motor convertor changed. That is to say, that the frequency to the motor is controlled by the actual motor speed and because of this, the motor can never get out of step with the convertor. It is locked into synchronism at all times. This holds throughout the speed range, from zero speed to top speed.

The LCI utilizes a DC link inductor sized to allow the drive to operate as a current source. This provides for a high level of protection such that the drive can survive a short circuit on its output without thyristor failure.

This drive can easily achieve high power levels because it uses natural commutation on both bridges and it uses SCR's. Natural commutation is accomplished on the supply bridge by the action of the incoming supply waveforms.
This is the same as a DC drive. The machine convertor can also achieve this benefit because the synchronous motor is operated at a leading power factor. This allows the SCR's to be commutated solely by the waveforms present on the stator terminals of the motor, its generated emf. If this were not so, then additional components for forced commutation would be required. These components detract from the convertor in terms of space, cost, power consumed and reliability.

Because the LCI does not have these items, it is very easy to build up to higher power levels by merely adding cells in parallel or series.
(See Fig. 5)



METHODS OF INCREASING POWER

FIGURE 5

Additionally, the LCI uses SCR's. The SCR's used are slow turn off, or convertor grade. These cells are readily available in high current and voltage ratings at reasonable cost.

DC drives at very high power levels are severely limited in speed. (See Fig. 6)

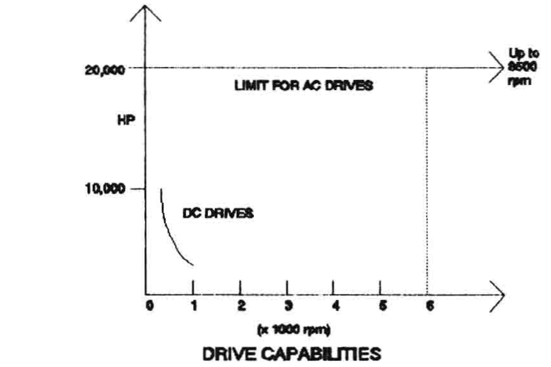


FIGURE 6

Because of the brush gear required, as the power goes up the speed comes down. LCI's are not limited by this and there are installations in operation up to 20,000HP and 6,000RPM direct drive.

One of the newest advances in AC drive technology today is the implementation of VECTOR CONTROL. This technology is available because microprocessor based regulators are able to do the vast calculations required and to do them with very high speed. It is interesting to note that the LCI drive is a vector control drive by virtue of its basic operation.

<u>SYSTEM PERFORMANCE AND BENEFITS</u>

Because of this combination of a synchronous motor and the naturally commutated thyristor bridges, this system is able to achieve benefits that are not available or are only available by additional circuitry and complexity in other technologies.

The synchronous motor is brushless. (See Fig 7)

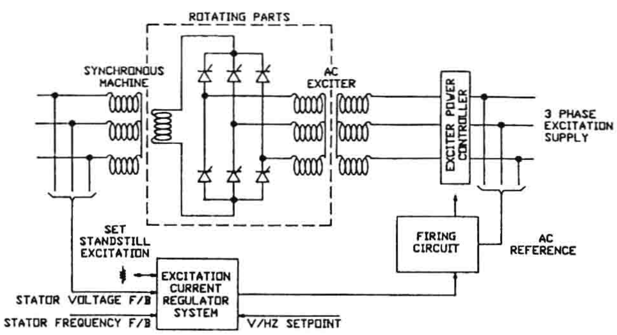


Figure 7

Field current is achieved at zero speed by the use of a three phase exciter winding, both rotating and stationary. Rated torque is available anywhere from zero to base speed. (See Fig. 8) The motor is always in synchronism.

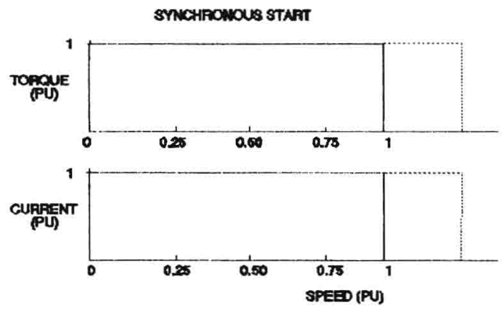


FIGURE 8

Thus, the full pull-out torque of the motor is available as long as the convertor is sized for the current required. The current limit setting of the drive is used to control the maximum current and torque allowed. This provides protection to the electrical circuits, protection from thermal overload and protection to the mechanical system.

Soft start is provided even at full torque. There is no inrush. The amount of current drawn is only that required to power the load plus make up the losses. This is easier on the electrical and mechanical system than across line start motors and it allows for unlimited starts of the motor.

The equipment can achieve power dip ride through and spinning motor restart. If the voltage dips the drive can continue to power the load. At some point it will be necessary to phase the drive off before the low voltage causes coils to drop out and control to be lost. Therefore, typically, at 85% voltage and below, the supply bridge will phase off and the current will go to zero. At this point the motor and load will coast.

If the control circuits are separately powered, and the voltage is maintained, the regulator will stand by waiting for the voltage to return. When it does, the drive will find the spinning motor, synchronize the machine bridge firing with motor speed and position, and then the supply bridge will phase forward and power will be softly reapplied and the motor will return to the desired speed.

If a drive "STOP" is initiated for any reason and the operator wants to immediately restart he can do so no matter what the motor speed is. The drive will restart and return the motor to desired speed all under soft control with no shocks to the electrical or mechanical system.

This system has high efficiency. A typical wire to shaft efficiency is 93%. This includes all losses including the isolation transformer, convertor and regulator, dc link choke and motor. The control of this system is accomplished by an all digital, microprocessor based regulator.

While this technology is not unique to a synchronous motor drive, it does provide all the benefits. Some of these benefits are:

1. No drift with time.
2. No drift with temperature changes. Typical speed regulation is 0.3% without any feedback device added to motor.
3. Flexibility to make changes in software instead of hardware.
4. The size required to do the same function can be reduced compared to analogue or conversely for the same size, much more complicated circuitry and control can be achieved.
5. Replacement cards will be set up exactly as the card removed because the settings are made by digital information rather than a potentiometer or discrete component.
6. The same set of regulator hardware can be used for different applications and for different drive technologies. Thus the same circuit card can be used for a DC drive as well as for an AC drive. This has the advantages of scale, the use of already proven hardware, and eliminates the need to retrain service and maintenance personnel. This can be achieved because the changes are made in software.
7. Keypad access to change parameters.

Various other benefits are available with no additional parts. These are inherently available and can be initiated by simple software changes. The LCI drive is a 4-quadrant drive. (See Fig.9)

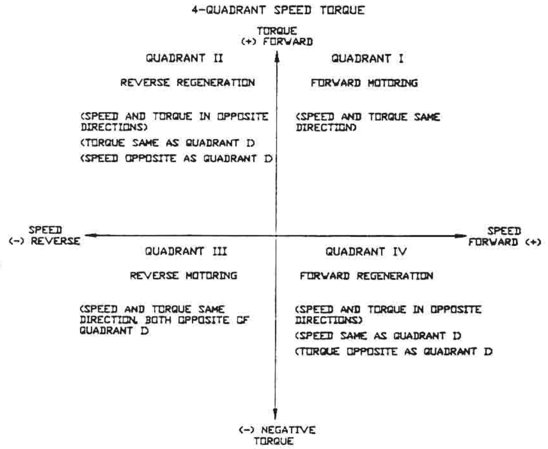


FIGURE 9

That is, the drive can power the motor in the forward or reverse direction. In addition the drive can regenerate in either direction. Regeneration can be used to extract power from the load and return it to the supply system. This feature is used in the case of overhauling loads to hold back the driven apparatus, or to slow down the load faster than would occur by unpowered coasting. This may be needed to achieve the process control required or for emergency stop.

This drive can be operated above base speed in constant horsepower just as a DC drive would be used.

Availability of the equipment is very high. The motor is brushless, the power converter is simple due to natural commutation, and the regulator is free of drift and much of the complexity is in software, not in wiring and solder joints. Thus the mean time between failure, (MTBF), is high. If a failure does occur the mean time to repair,(MTTR), is low. The microprocessor, with features like history recording, and first fault annunciation, allows quick troubleshooting. Then, the use of modular construction allows for quick repair. The combination of high MTBF and low MTTR provide for AVAILABILITY of the equipment to reach 99.9% and higher.

APPLICATION CONSIDERATIONS

Anytime an electric variable speed motor drive is installed there is a need to consider how the new equipment will interface with the existing plant. This is especially true when the new equipment is of the size we are talking about here, where power levels can reach thousands or even tens of thousands of horsepower. These considerations should be addressed at lower power levels as well, but at these higher levels they are mandatory. This type of drive draws square waves of current from the electrical supply grid. These square waves are made up of harmonics. The harmonics are at a variety of frequencies and magnitudes. These frequencies can interact with the supply system and can affect other equipment being fed from the same supply. Problems can vary from being non existent, to being a nuisance to outright failure of equipment.

This situation is not unique to LCI drives, instead it exists in any three phase rectifier, whether phase controlled or fixed and it does not matter who the manufacturer is. The drive supplier can give advice and information but the problem is not a drives problem, it is a system consideration. The important point is that the harmonics should be studied early on, long before the drive equipment arrives. This way, if needed, a solution can be decided and any hardware procured and installed with the drive.

Any variable speed drive system, at least of the size we are talking about, should have a torsional study done in the early stages, and certainly before the drive equipment arrives. Just because the same application was free of any torsional problem, when driven by constant speed, this does not mean that it will be trouble free under variable speed control. In addition, the LCI does produce some torque pulsations. A torsional study should be done and if a problem exists the majority can be solved by the inclusion of a resilient coupling.

The important aspect about harmonics is not that they exist but, instead that they are addressed. The drive supplier, the driven equipment supplier, the user, and the engineering group involved must work together to exchange information and to insure that the proper studies are completed and that the proper system solution is implemented as part of the project.

Various configurations are available to suit the application. Single channel, six pulse is the most common. Dual channel redundant schemes are used where the process cannot be interrupted even momentarily. Constant speed, across the line bypass can be used. Twelve pulse schemes can be used to reduce harmonics on the input or torque pulsations on the output or both. If there are multiple drives, a standby converter can be installed to take the place of a failed duty convertor, either manually or automatically.

One use of the LCI drive is as a retrofit, that is to use an existing constant speed synchronous motor, and insert a convertor between the supply and the motor, and run the process at variable speed. One manufacturer has done a number of these retrofits including one with an 8,000HP motor.

INSTALLATION EXAMPLE

There are a number of LCI drives on Banbury Mixers both in Europe and North America. We will describe one project, which happens to be in the US, involving multiple units, all of identical design.

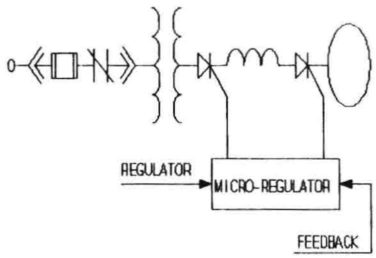


FIGURE 10

The equipment rating is 2,000HP continuous with an overload above the base rating. Each equipment consists of an input isolation transformer, convertor/regulator, DC choke, and motor. (See Fig. 10).

The isolation transformer steps down the supply voltage to the level utilized by the SCR bridges. The transformer is double wound and the impedance is sized to coordinate with the overcurrent protection of the SCR's. A faraday shield is incorporated to aid in electrical noise reduction.

The convertor is six pulse design in both bridges. The convertor design uses a single SCR in series in each leg of the bridge. The input voltage to the supply bridge is 750VAC. A microprocessor regulator performs all of the control functions including control loops, firing pulse generation, protection, data logging and history recording. Interface with the outside world is available through analogue and digital I/O and through a serial link.

In this installation, signals such as stop/start use the digital I/O and are received from a local programmable controller,(PLC). Three analogue signals are connected to the analogue I/O. Speed reference into the drive and actual speed back to the PLC are done via 4-20 ma. The microprocessor, using values of current and voltage available in the drive calculates the kilowatts being delivered to the motor on a continuous basis. This is then fed to the PLC via 0-10V where the signal can be used to monitor what is going on in the mixer. This shows an example of how the micro's flexibility can be used to provide a special function.

The DC link choke is located in a cabinet by itself. Because it is an integral part of the drive overcurrent protection it is of an air core design. The input transformer and link choke can be in the same line up but they do not need to be.
The motor is totally enclosed to keep out carbon black and other dirt. An internally mounted heat exchanger uses plant water to remove heat from the enclosure. A constant speed blower circulates air inside the enclosure and across the heat exchanger to provide cooling that is not tied to the speed of the motor rotor. As an added degree of protection the enclosure is pressurized with plant air to provide a slightly positive pressure inside the machine.

The first of these units was commissioned in spring of 1990 and has been in continuous service since. Up to the time of this writing a total of seven equipments have been commissioned. Two more units have been delivered and by the time this paper is presented some of them will be in service. In addition to these nine units, additional drives of the same design have been placed on order. The drives in service have been running for about 18 drive months. To date the performance has been very good with no failures reported over the six equipments. The availability is at or near 100%.

The operation of the LCI drives to date is perhaps no different than could be expected of any properly designed and properly applied variable speed electric drive. There are some items which are seen as positives for the long term, some of which are not available with other technologies.

1. The motor is brushless.
2. The system handles the rapidly varying load of the Banbury Mixer well.
3. The drive has been very reliable in the Mixer application.
4. The drive is relatively simple.
5. The microprocessor regulator is a major plus in terms of long term drift regarding set points for protection, regulation, etc.
6. Communications with the plant PLC is easy.
7. The ability to calculate the KW of the load with accuracy and consistency is a plus over some of the past methods.
8. When problems do arise the micro fault annunciation and history recording will minimize troubleshooting.

CONCLUSION

This paper has shown that a technology is available to drive the Banbury Mixer load at variable speed and to do so reliably and at high power. This technology also overcomes some of the disadvantages of previously used technology.
this type of drive has been applied with success in a number of Mixer applications. This technology can also be applied to other arduous duties in the Rubber and Plastics industry such as extruders, pelletizers, and other constant torque or variable torque loads.

THE APPLICATION OF A VECTOR CONTROLLED AC DRIVE FOR INTERNAL BATCH MIXING OF RUBBER COMPOUNDS

by
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Abstract: The mechanism of processing rubber compounds in an internal mixer creates a tough, demanding application for which a vector controlled ac variable frequency drive was found to be eminently suitable. A 1500 Hp, 2300 volt, current fed inverter was successfully applied to this common industrial process. This paper describes control strategy, drive construction and operation, and application considerations. Operating results will be discussed.

INTRODUCTION

Most of the rubber compounds used today are processed in internal mixers typified by the Banbury mixer. Uniformity of product is controlled by variables such as loading sequence, rotor speed, ram position, accurate sensing and control of temperature during mixing, and control of work input during the mixing cycle.(4) In 1989, Kleen-Tex, Inc., a custom mixer of rubber compounds with a capacity of 24 million lbs/year, undertook a plant renovation. Besides increasing capacity and efficiency, improved mixer control was sought in order to improve quality and uniformity of product and to expand existing mixing capabilities to include a broader variety of compounds.

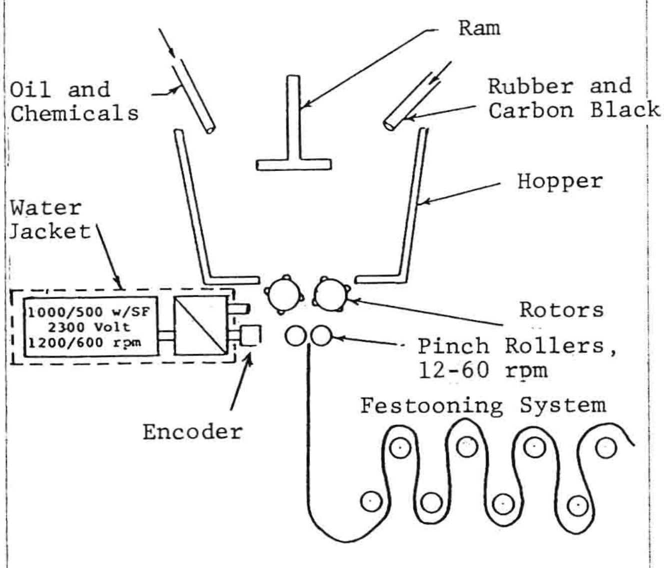

Figure 1. Process Diagram

PREVIOUS PRACTICE

Existing equipment included an 11D Banbury mixer, and a 1000/500 hp, 1200/600 rpm, 2300 V, high service factor induction motor controlled with contactors which connected either the high speed or low speed windings across the line. The motor was enclosed in a water jacket for cooling. A gear unit provided a 15:1 speed reduction ratio for mixing speeds of 40 rpm or 80 rpm. See Fig. 1 for a process diagram.
The mixer had been in service for many years and was beginning to exhibit the effects of clearance increase due to wear. Longer mixing cycles are required as clearances increase in order to compensate for the resultant decrease in power level. Due to the degree of wear present, it was scheduled to be replaced with a Skinner S-268 mixer.

In order to diversify and extend plant mixing capabilities to a greater variety of products, it was decided to upgrade the facility to include variable speed control. This enables precise selection of the optimum speed for mixing each type of compound so that the material does not reach a specified temperature limit before it is uniformly mixed. A significant advantage in utilizing an ac drive was that the existing ac motor and gear reducer could be employed.

Another advantage of a variable speed drive is a reduction of peak energy cost. Line starting of a fixed speed motor results in a high inrush current and therefore high utility costs due to peak power requirements. High rotor losses are incurred in the motor with each line start. A VFD provides a soft start. The motor draws no more than drive rated current during starting. This extends motor life, reduces wear, and prevents power line dips.
A 1500 HP, 2300V, vector controlled, current source Variable Frequency Drive (VFD) was applied to the existing motor, which was connected as a 1200 rpm, 1000 hp motor. The existing contactors were left available for reconnection to the motor for use during startup. They may also be used in the event of drive failure or during scheduled maintenance. This permits some types of compounds to be processed while the VFD is not in service.

DRIVE SELECTION AND PERFORMANCE REQUIREMENTS

Based on wide general industrial acceptance of VFD's, the mature technology, and rugged design of the current source drive, a high degree of reliability can be expected. Maintenance, and troubleshooting with the aid of standard VFD diagnostic features, can be performed by qualified plant personnel. The factory project engineer and service personnel are readily available to provide continuing technical support.

Standard, frequency programmed ac drives have been applied for noncritical speed control of pumps and fans where loose speed regulation is required, and starting torques are relatively low. Standard drives vary the motor speed by open loop stator frequency control and maintaining a fixed volts per hertz ratio throughout the speed range. Speed regulation is motor and load dependent (1-3%) and there is no direct control of torque, since torque is produced only when the rotor speed is slower than the speed of the stator flux. The stator frequency is directly proportional to the speed command and rotor speed varies with load.

The severe load conditions inherent in the duty cycle of batch process mixing demand a vector control

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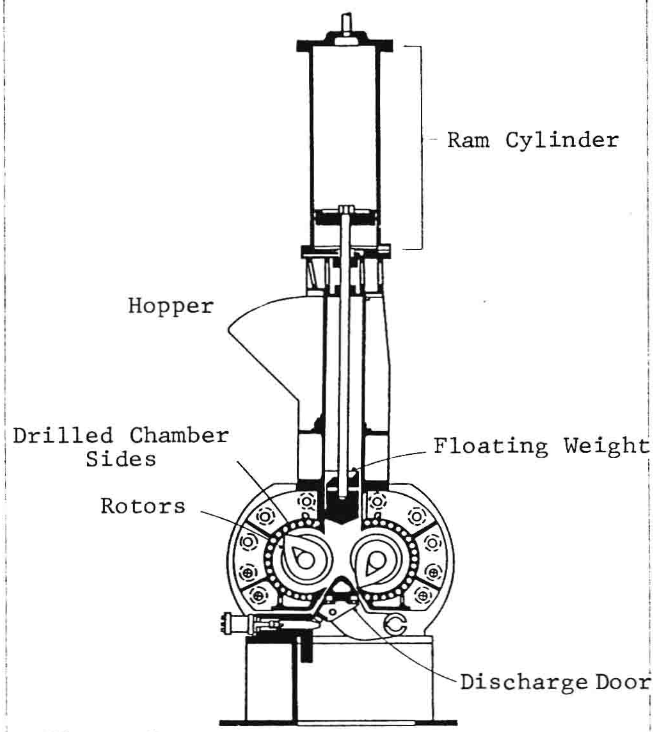

Figure 2. SKINNER INTENSIVE MIXER

strategy, also commonly referred to as field oriented control. This type of control has been described in a paper at an earlier Rubber and Plastics Conference (1) as well as other publications listed in the references.

A specific work input is needed to yield a desired quality of product within a specified cycle time. Power is directly proportional to both torque and speed. A vector controlled drive has directly controlled outputs of current, slip, and torque angle. With close regulation of rotor speed, and a rapid response to sudden changes in load torque, speed droops which can result in an inconsistent batch are avoided. Sufficient torque is provided in spite of the severe load fluctuations so that optimum power can be delivered throughout the loading sequence, mastication, and mixing process.

The drive also must be capable of supplying up to 1.5 pu torque at standstill. If the batch cycle is interrupted by a power or equipment failure before the mixer is emptied, the load will be difficult to restart. It may not be possible to start or accelerate the motor with a standard frequency programmed ac drive. A vector controlled drive can generate at least 1.5 pu torque at standstill provided that the current limit is appropriately increased to 1.5 pu.

VFD DESCRIPTION

The variable frequency drive is rated to drive the 1000 hp induction motor with 150% overload capability. It operates directly from the plant incoming 2400 V utility power source without an isolation transformer. The supply to the VFD is fed through a load break fused disconnect switch and a three phase input line reactor which reduces the line notching common to all static power conversion equipment. The VFD input circuit includes surge arresters which provide overvoltage protection.

Extended speed operation up to 75 Hz is feasible, depending on motor parameters and load at the high speed. In this application, the drive is operated up to 66 Hz. The drive is an autosequentially commutated current source inverter (ASCI) with standard rectifier grade high voltage SCR's utilized in the converter and inverter power circuits. The power circuit can be divided into three sections: Converter, DC link inductor, and inverter.

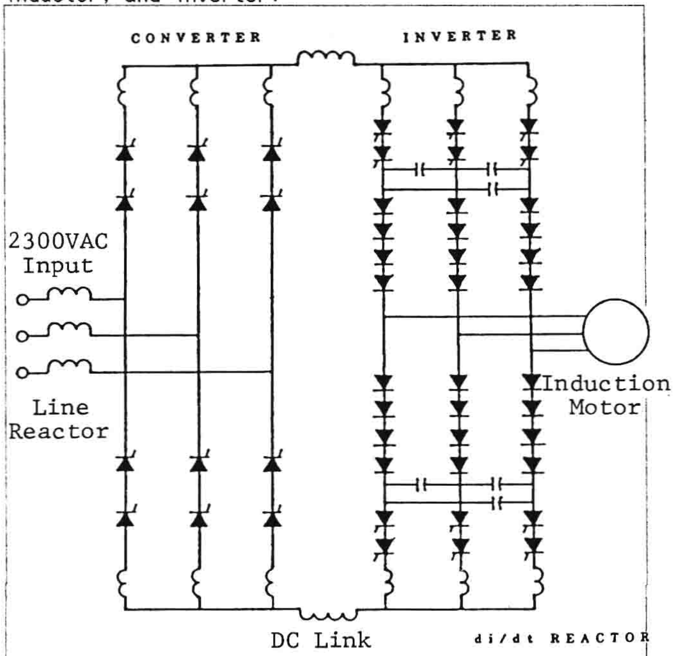

Figure 3. Simplified Power Schematic

The converter section is basically a dc drive that converts 2300 volts ac to variable voltage dc. A 2500 volt dc motor could be operated at variable speed from the converter output terminals. The average value of the dc output voltage is determined by the value of the ac input voltage times the cosine of the firing angle delay (alpha). Natural commutation, or "turn off" of the SCR's occurs when the next thyristor turn-on reverse biases the off-going device. The circuit is a 3 phase, full wave, fully controlled rectifier bridge. Two series connected SCR's and a saturable reactor are used in each leg of the converter. The reactors ensure voltage sharing by the two SCR's, and permit the use of devices which do not have precisely matched characteristics.

The converter and dc link inductor, or choke, together form a current source which supplies constantly regulated dc current to the inverter. The value of choke inductance is generally inversely proportional to drive horsepower. Therefore, a standard design 1500 hp drive would not be optimally designed to operate a 1000 hp motor. The dc link for this application was designed for operation on a 1000 hp motor and for future operation on a 1500 hp motor.

The inverter section sequentially switches the dc current from one phase to the next to provide a six step trapezoidal wave ac current to the motor. Each leg of the inverter power bridge consists of two series connected thyristors, four series connected high voltage diodes, and a saturable reactor. The

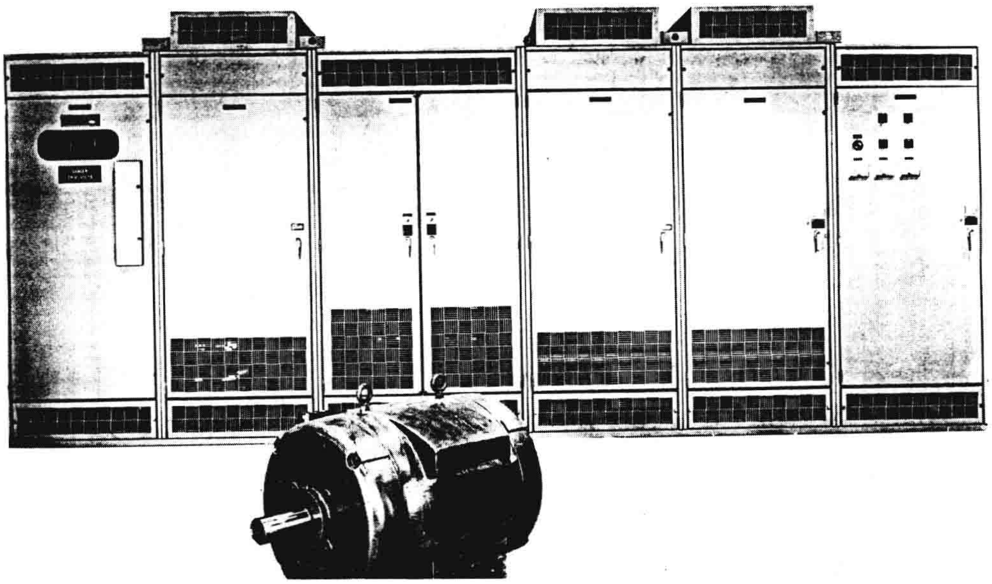

Figure 4. 1500 Hp VFD Enclosure

reactors are in series with the thyristors to limit di/dt and to ensure voltage sharing. Since the inputvoltage to the inverter is dc, natural (line) commutation cannot occur. Autosequential commutation, in which the next thyristor in sequence is fired and automatically commutates the previously conducting device, is employed. The positive and negative inverter bridges each have 3 phase capacitor assemblies, which together with the series connected power diodes make up the commutation circuit. When the diodes are forward biased, they permit the energy in the motor leakage reactance to charge the capacitors, and when reverse biased, they block capacitor discharge into the motor windings. The value of capacitance is selected based on motor performance data, and is chosen to provide sufficient commutation energy and to limit peak voltages on the SCR's.

The unit is air cooled with blowers exhausting into the electrical room. The NEMA 1 enclosure is a 6-cabinet, 19 ft long lineup, installed along one wall of the electrical room. Drive components are front accessible.

DESCRIPTION OF OPERATION

A rotor shaft speed and position feedback signal is supplied to the VFD vector control circuit by an encoder which is typically mounted on the motor shaft. In this case, the motor is enclosed in a water jacket and the shaft is not accessible. The encoder was therefore mounted on the gearmotor shaft. The rotor speed is compared to the speed reference and an error signal is developed. This error signal becomes the torque command, which together with pre-programmed motor slip information, is used to adjust stator frequency so that slip appropriate to the torque is maintained. The encoder pulse train is also used to determine rotor position in relation to the orientation of the stator MMF. Then the torque angle and stator current needed to develop the desired torque is calculated. Speed regulation of 0.5% of base speed and dynamic torque response of 10 to 20 ms is achieved.

A typical batch cycle duration is less than four minutes. Operating speed, typically between 0.5 to 1.1 pu, is held constant throughout the cycle. The mixer is initially accelerated, unloaded, to a required speed for a particular compound. As slabs of raw rubber and compounding ingredients are tossed into the hopper, severe load fluctuations occur. While mastication and mixing are taking place, a piston operated ram is repetitively lowered and raised to compress the compound. See Fig 1. The ram pressure causes the most severe repetitive load torque oscillations. Swings between 40% and 130% of rated motor current are typically observed. The duration and magnitude of peak current is dependent on the process variables such as material properties and required ram pressure.

The vector controlled drive incorporates a proportional and integral speed regulator which generates a torque command. The proportional and integral gains were adjusted during start up to maintain a quick time response to step increases in load while minimizing speed overshoot. The VFD output torque limit adjustment was set at 1.3 pu torque. When this limit is reached the drive attempts to shed load by reducing stator frequency, thereby reducing rotor speed. An inverse time overload trip would occur if load torque did not subsequently decrease within the timed period. The setting is high enough to allow the rotor speed to be maintained during typical peak load conditions, and protects the drive and motor against overloads of higher than expected duration. The motor is equipped with resistance temperature detectors which are interfaced with a programmable logic controller (PLC) and an alarm.

As the compound temperature and elasticity increase, the current peaks gradually decrease below 1 pu. For the remainder of the batch cycle, the current remains at approximately 0.6 pu. When the compound reaches the desired temperature it is abruptly discharged through a door at the bottom of the mixing chamber. The motor and drive briefly regenerate power at this time. The current source VFD converter power circuit is inherently regenerative. It responds to the reversed voltage polarity of the inverter bus by phasing back SCR gating signals more than 90 degrees. The drive and motor then run unloaded at preset speed until the next batch is introduced.

VFD operator controls are available at the drive and at the mixer control panel. Automatic control is through a user programmed PLC which generates a 4-20mA speed command. VFD outputs which are utilized at the mixer control panel are indications of motor speed, current, and power. A VFD trip light and reset pushbutton are also installed for use during troubleshooting or in the event of a nuisance trip. A 4-20mA output speed signal is used to control the process lubrication pump.

SPECIAL CONSIDERATIONS

The requirements imposed by a wide range of load current, and a wide operating speed range can be met with an appropriately rated standard NEMA B motor and drive. In this application, however, the motor had an unusually low magnetizing or no load current, which limited the maximum operating frequency. The inverter power circuit relies on energy stored in capacitors to commutate (turn off) the SCR's. The duration of capacitor recharge is inversely proportional to dc link current. When the motor is operating at high speed and light load conditions, the time required to recharge the capacitors may be so long that when the next SCR turns on, the voltage on the capacitor is not yet high enough to reverse bias the previous SCR. It continues to conduct current and a commutation failure occurs. An attempt to decrease the duration of commutation by reducing the capacitor values caused the peak output voltage to increase to unacceptable values, and also reduced the commutation energy available for starting under heavy load.

A delayed ringup circuit (2), comprised of air core inductors, SCR's, and a gating circuit, can be used with low voltage drives to accelerate commutation to permit operation up to 120 Hz. It is not economically practical to implement this at medium voltage. Instead, an additional load of 0.1 pu current was connected at the VFD output terminals. This was provided by a 3 phase reactor and resistor assembly housed in a 3 ft wide enclosure.

After about two months of continuous service on the VFD, a dc link choke failure occurred. The cause was found to be a construction defect and was corrected by the vendor within one week. During this time, the plant remained in operation by using the original contactor control.

APPLICATION CONSIDERATIONS

Motor Derating and Service Factor

For continuous operation at less than 50% speed, a motor which does not have external cooling should be derated so there is adequate cooling at full load. In addition, the harmonics in the current waveform of any solid-state variable frequency drive cause increased heating in the motor. Therefore, a standard motor should be derated to provide the required load current with a 1.15 service factor.

Line Harmonics and Power Factor

All static motor drives, including dc drives, cause voltage distortion on the power distribution systems to which they are connected. The system voltage distortion levels are dependent on system impedance as well as harmonic producing loads. If the power source system impedance is low, the voltage distortion may be negligible. As a rule of thumb, if the ratio of available short circuit kVA to VFD kVA is greater than 50, the total harmonic distortion generated by the drive, as defined by IEEE 519-1981, will typically be less than 5%. Recommended limits for medium voltage systems are 5% for general applications, and 8% for dedicated systems which service loads not affected by voltage distortion(5). A harmonic analysis can be performed to determine whether a harmonic filter is indicated. Most problems occur when power factor correction capacitors cause the system to be in resonance at a significant harmonic frequency. In general, if total capacitor kVAR is greater than 10% of the rated kVA of the system, resonance problems should be considered. A tuning reactor in series with the capacitor bank may be required.

VFD input power factor is approximately equal to the motor power factor times the per unit operating speed. Utility metering will measure the VFD input displacement factor as power factor. If power factor correction is required, power capacitors in series with a tuning reactor can be connected at the VFD input terminals.

CONCLUSION

This paper has presented the successful application of a vector controlled ac drive to internal batch mixing of rubber compounds. A vector controlled induction motor drive has been shown to be a practical alternative to a dual armature converter dc drive, which is currently the standard in the rubber and plastics industries. It is expected that ac drives of this type will gain wider acceptance as concerns about reliability and performance diminish with experience.

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Advanced CIM Techniques

Rubber Mixing

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Synopsis

Rubber mixing facilities are experiencing the common pressures of our current manufacturing environment. They require constant improvement in the consistency and quality of the products produced. Plus they demand accurate trace-ability of raw materials and the data to substantiate each phase of the process and procedures involved. This paper will show how Computer Integrated Manufacturing (CIM) techniques are applied to meet these demands and effectively integrate existing procedures into the CIM environment.

The following functions are typical of the rubber mixing process and will be discussed within individual sections of this paper.

- Production Scheduling and Tracking.
- Recipe Management and Maintenance.
- Ingredient Batch Testing and Quality Control Data Collection.
- Inventory Management and Tracking.
- Accurate Automatic and Manual Material Dispensing/Weighing.
- Critical Weighment/Ingredient/Lot Data Collection.
- Batch Identification and Tracking.
- Critical Mixer Process Control/Data Collection.
- Alarming and Logging of Procedural and Process Deviations.
- Operator Procedure Tracking.
- Access Security and Validation.
- Long-Term Data Storage and Management.
- Data Presentation and Reporting.
- Management Information System Link.

Introduction

We are all aware of the promise of CIM. With no idle operators or machines suffering downtime, we can streamline material handling, from raw materials to the finished product. This gives us the double benefit of lowering overall production costs and increasing product output from existing resources.

Because we have accurate, timely data, our rocket scientists can refine the production process to provide efficient resource planning and adjust schedules flawlessly. Consequently, there are no unhappy customers. Word-of-mouth spreads our company name like wildfire, increasing our market share and expanding the market acceptance of our products.

The entire industry is focused on our continuing success and our stock price sets new record highs each week. As our reputation and fortunes expand, our company has a golf tournament named for it and we all get 50 yard line seats at the Rose Bowl.

This is the *promise* of CIM.

CIM is like any other high technology tool. We know that the technology is sound and that it serves a useful, maybe even vital, service. But just having the technology does not guarantee success. We need the personnel who understand this advanced technology intimately. And we need the vision to employ the technology in the right place at the right time. Any high tech tool, without the correct people and implementation, may just sit on a shelf and collect dust. That's a return on investment I'd hate to explain to anyone.

At some point, I'm sure you will be able to buy a small black box that plugs directly into your mixer and controls your production process. Your job then will be to turn off the factory lights and wait for the money to roll in. But if you don't have the patience to wait for that miracle device, or if your customers keep bugging you for product and information, maybe we ought to discuss how to use today's advanced CIM techniques in the rubber mixing process.

CIM Components

CIM has two components, computer resources and manufacturing techniques.

Advances in computer hardware and software occur so frequently that the best way to track current advanced techniques is through periodicals. Even then, the so called state-of-the-art zips away from us at the speed of light. The cutting edge foretold in magazines is usually surpassed by the time the ink dries.

Advances in manufacturing are even harder to track. Obviously, improvements in a production process fall under the category of trade secrets. If companies or academics are benevolent enough to disclose what may be a clear market advantage, all manufacturers benefit. But at what cost to the sponsor of the article?

Consequently, factory engineers and managers develop their own highly creative manufacturing solutions and look to the CIM integrator to implement the plan. This paper addresses advanced CIM techniques as they may be applied to those creative solutions for the process of mixing rubber.

I plan to give you a quick summary of today's advanced CIM techniques. I then want to walk through the major steps of the rubber mixing process and suggest how these advanced techniques can provide a solution. I will provide justification for the proposed solution and in some cases, offer alternative techniques.

Remember, successful deployment of CIM is determined by the proposed mission and the way you do business. There are no easy solutions, only profitable ones.

Today's Advanced CIM Techniques

Many of the advances made in the computer field have direct application in providing CIM for the rubber mixing process. These include:

- Smart Systems
- Gee-Whiz Graphics
- Data Handling
- Software Maintenance tools
- Improved Operator Interface

Smart Systems

Smart systems that provide artificial intelligence (AI) and hypertext links have been promised for years. While research still continues on AI, hypertext is available today.

Hypertext has been described as a seamless carpet of knowledge. Hypertext files contain help screens or other information. While reading the file, operators can call up an additional file quickly through hypertext links. The second file may also contain topics with hypertext links. These topics can lead to more information, can access data bases, or can begin other computer programs.

Hypertext topics help operators to customize the level of information they need from their help files.

Gee-Whiz Graphics

Computer programs are moving to Graphic User Interface or GUI screens. By providing pull down menus, pop up windows, point and shoot selection, and graphical process renderings, these programs reduce the time it takes for integrators to create a CIM application. Additionally, you can include bitmap graphics (i.e., CAD drawings) of schematics or production flow diagrams. It is possible to edit and colorize the graphics, and to mix them with other GUI objects to produce dynamic graphic screens.

Plus advances in computer processor throughput make computer animation inexpensive, in terms of both dollars and processor time. Animation can, of course, improve process simulation and monitoring.

Data Conversion and Storage

Collecting data is relatively easy for any computer system. Making that data available and useful to decision makers is the frosting on the cake.

Your CIM system has to talk to controllers on the factory floor, systems in other manufacturing cells, supervisory systems in the vice president's suites, business systems in MIS, laptops in accounting and presentation equipment in the board room. Plus as the world is wired together into a global village, primary and secondary suppliers, and even customers will want to send and receive computer information.

Your CIM system becomes part of both local area networks (LAN) and wide area networks (WAN). The system must be able to convert data to the correct format and send it to the appropriate system intact.

Suddenly your CIM computer's duties expand to providing server/client functions, data conversion and communication protocol translation. Although this puts more demands on your CIM software, the benefits you enjoy are just now being discovered. One example is a scenario where the lab perfects a recipe and within seconds, factories around the globe are producing a better product.

Of course, all of this data must be stored somewhere. Again, recent advances in optical and tape mass storage devices makes it easy to save all the little ones and zeros. The hard part is developing programs that can help you assess SPC trends and business cycles that are hidden in that digital landfill.

Software Maintenance

Allen Turning, a pioneer in the field of digital computers, once dreamed of a robot that could repair itself. The robot would diagnose its own trouble, retrieve the necessary parts, and bring itself back to full operation. Dream on, Allen.

System maintenance, whether for the computer or production equipment, is still a fact of life. And the CIM software is no exception. But, advanced CIM techniques eliminate the expense of dedicated application programmers.

Modern CIM software offers the advantage of application enablers. Instead of spending lots of time and money building custom software solutions, CIM packages can supply applications and interfaces that have proven themselves in facilities just like yours. It is then a simple, and less expensive, task to adjust this end user configurable solution to your particular production process.

This is the benefit of "clean hands" application development. Although any good programmer can get down with the bits and bytes in your system, remember that time is money. While a custom programmer is busy making the computer chips dance, you're not making rubber and the phone is starting to ring. With an end user configurable application, maintained by your production department, you can quickly custom tailor your system for your factory.

Today, software should provide high-level, specialized commands. With a few simple lines of these commands, your people can create application revisions that would take a custom programmer hundreds of lines of instructions. Any good CIM package should give you this leverage.

Improved Operator Interface

Operator interface is just a fancy way to say helping your people work smarter. This includes improved data entry techniques that eliminate the need for operators to type information into computers. Bar-code readers, automated scales and thermostats, optical character readers, and even voice entry systems make it easier for the information to get from the factory floor to the various computers.

Hypertext and GUI systems can reduce new operator learning cycles. And improvements in system security can reduce the chances of unauthorized access to your data or automation programs.

Any good CIM implementor will recognize that the most valuable asset in your production process is your people. Advanced CIM techniques make their jobs easier and help them to focus on the task of generating revenue.

Rubber Mixing Process

Let's turn our attention to the rubber mixing process. We'll take a look at the steps in that process, suggest some advanced CIM techniques, and explain why those techniques make sense.

The process steps are:

- Scheduling and Tracking Production
- Recipe Management
- Ingredient Trace-ability
- Inventory Control
- Material Dispensing
- Critical Ingredient Data Collection
- Batch ID and Tracking
- Mixer and Mill Data Collection
- Operator Accountability
- Data Management
- Statistical Process Control (SPC)
- Data Reporting
- The Link to MIS

Scheduling and Tracking Production

We begin with production scheduling. Scheduling is the production step that can benefit most from smart systems. Generally, Manufacturing Resource Planning (MRP) systems do not address the myriad of concerns for planning efficient, cost effective production.

A smart system can add additional intelligence to that decision making. You can "teach" the system which production rules you want to consider in your scheduling.

For example, what schedule involves a minimal amount of material handling, so that we're not moving raw material in and out of the staging areas all day? How can we schedule batches from similar compound families to reduce the time and cost of cleanout batches? By calculating estimated completion times for each batch, how can we divide the production between available mills and mixers? Can we give priority to final batches that incorporate previously mixed master batches, so we're not carrying WIP inventory inefficiently?

And, of course, the most important question:

Given this list of concerns, devise the optimum schedule now before the shift begins, and be prepared to reconsider the schedule as demand changes. This is the benefit of smart systems; Real answers to real questions using real time data.

Recipe Management

Certainly, storing and distributing the most recent recipe is a big advantage of CIM. You must ensure that the rubber you mix in Glasgow is exactly the same as the rubber you mix in Melbourne. Using local area networks or LANs, or even wide area networks, called WANs, you can be sure that your procedures and ingredient amounts are consistent.

But that's the easy part. Let's explore some advanced CIM techniques.

The compounder creates a recipe by selecting predetermined steps from a point and shoot menu. Steps such as ADD BLACK POWDER or MIX TO 110 DEGREES are assembled into a recipe. This reduces data entry time and guards against improper commands.

Now suppose a compounder creates a recipe that charges 50 lbs. of powder into a mixer and then orders the discharge door to open. (This is a grossly obvious error, but it is an example of a definite sequencing problem.) An intelligent CIM system can identify even subtle errors and report them to the compounder. It can even suggest ways to correct the recipe. This solution reduces the time spent troubleshooting problem recipes. Your system must also ensure that a flawed recipe doesn't replace the good recipe that you have stored.

Here's another example. When you create a recipe, the ingredient proportions are entered in parts per hundred. During production, you can specify the final batch weight for this recipe. Then your CIM system calculates the correct target amounts and tolerance levels for each ingredient. You don't have to create a new recipe for every different batch size.

Ingredient Trace-ability

I hope that the raw material you buy is always within spec. And I also hope that every batch you mix serves you and your customers well. But I have heard of a case or two where one bad ingredient fouled an awful lot of rubber.

As you test each lot of your raw material, your CIM system can collect information on that test result and link it to the batches you mix with that ingredient. Your CIM system, coupled with your existing business system can provide you with reliable trace-ability. You can track any product you mix to the specific vendor and lot number of any of the ingredients. You always have an accurate assessment of the quality of each ingredient and the portion used in any one batch.

Inventory Control

There is no doubt that Just In Time inventory management has a beneficial result on your cash flow and your profits. But one of the trickier aspects of JIT is trying to track your production schedule and still have time to make those inventory decisions.

Today's advanced CIM systems provide real answers in real time. That means accurate information right now. You get measurements of usage, waste, and projected shortages. You can also track inventory amounts, either warehoused or currently part of work-in-progress (WIP).

By tracking ingredients and projected schedules, your CIM system can help you determine cost per batch, present availability, and future needs. Your system can hand this data to MRP systems or even to laptop spreadsheets. That way, you can wrestle with "What if..." analysis to maximize your inventory vs. cash position.

Material Dispensing

The positive effect of CIM on the material dispensing area of rubber mixing is universal. CIM can integrate and control the full range of automated, semi-automated, and manual material dispensing techniques.

Consider a sealed minors dispensing system that contains 40 bins. Your system can read a recipe and unlock the correct bin for an operator only when the recipe calls for it. A digital scale can connect to your CIM system and ensure that the weighment is within tolerance. This kind of semi-automated dispensing improves accuracy and can keep inventory pure. These systems, with their small "footprint", use a minimum of factory floor space to maximize your facility, and provide demonstrable control over ingredient and lot integrity to your customers.

Even totally manual dispensing systems can benefit from advanced CIM techniques. The addition of bar code readers and digital scales reduces the time and error potential for reporting weighments. The operator can work more efficiently and you can have accurate information, available right now.

Critical Ingredient Data Collection

Critical Ingredient data collection is all part of the "paper trail" that CIM provides to guarantee trace-ability. The system remembers what was measured, when it was measured, and what batch was created using those materials. Again, you have real answers in real time.

Batch ID and Tracking

And your tracking need not stop with the raw materials. You can identify a final batch and continue comprehensive tracking. That unique ID for a single batch of rubber can become the lot number for the next step of the manufacturing process.

Or in some cases, the mix creates a master batch. The master batch becomes an ingredient in a final batch, mixed at a later date or even a different location. Your CIM system provides an interlocking web of information from the final to the master to the raw ingredients. You can follow any strand of that web, from your final product, back to a single bag of powder.

Mixer Control and Data Collection

Along with accuracy in ingredient use, CIM provides the same level of consistency for process control. Consider the mix process.

There are 6 major process control parameters:

- Time (seconds)
- Batch temperature (degrees)
- Instantaneous power used (kilowatts)
- Accumulated power used (kilowatt hours)
- Ram pressure (PSI)
- Cooling water temperature (degrees)

Any well-constructed CIM system can measure these parameters. And having that data is important to process analysis. Flexible CIM systems can now use any logical combination of these measurements to trigger additional process steps. The accurate data collection of these parameters along with the ability to analyze trends across many batches, improve the decision making and SPC features of your smart system.

All of this assists your compounders with process analysis. And your control over the production process can improve significantly.