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THERMOCOMPRESSORS IN ACTION. AN OVERVIEW OF THE MECHANICS AND APPLICATIONS OFSTEAM.

PaperAge

Thermocompressors in Action. An Overview of the Mechanics and Applications of Steam Jet Compressors

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Thermocompressors are found in almost all paper mills, sometimes to simply boost pressure in steam mains, but generally to recompress and recycle blow-through steam in dryer drainage systems. Having no moving parts, very low maintenance, and utilizing both kinetic and heat energy of the motive steam directly, they are ideal for this primary application. But in practice there are many questions about both design and application of these unique devices.

Widely used in dryer systems for more than a half century, many thermocompressors in current use have been misapplied or badly sized. After a recent rebuild of the steam system on a large Southern paperboard machine, for example, eight out of eleven thermocompressors were wide open, consuming 400 lb. motive steam at maximum rates. Yet about 25,000 pph of blow-through steam that should have been recovered was blowing out to the atmosphere. In addition a substantial amount of condensate was being recirculated back into the dryers.

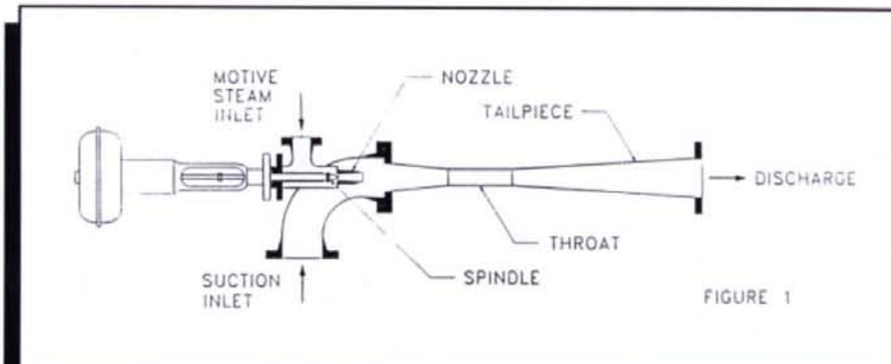

Figure 1 - Cross section of a typical thermocompressor

In a modern tissue mill with several Yankee dryers, the motive steam pressure is so low that the thermocompressors are really nothing more than expensive makeup valves. Except for a minor amount used to heat water, all of the blow-through steam from the Yankees goes to waste. A similar situation was investigated in a newsprint mill where an obvious attempt to utilize low pressure motive steam simply did not work. The thermocompressors supplied most or all of the steam in the main dryer sections, and blow-through steam losses from the dryers greatly exceeded condenser capacity.

The continued, though now obsolete use of thermocompressors to control DP (differential pressure across the dryers) prevents operation of most dryer sections at low pressures, produces huge steam losses on breaks and loss of control, and contributes to frequent flooding of dryers. Thermocompressor-cascade type steam systems are still in operation that waste as much steam as they are supposed to save. Mismatched thermocompressors commonly cause choking with reversal of response to control, deadband in

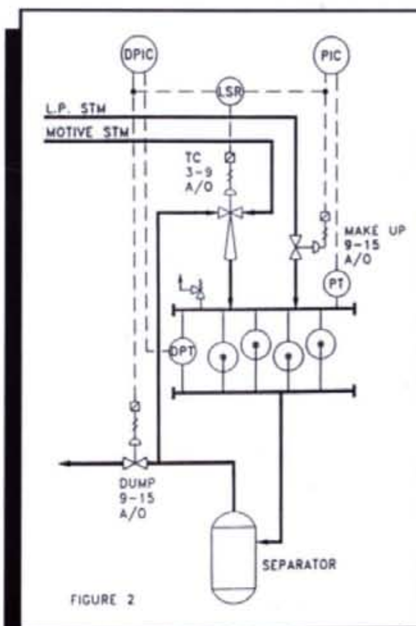

Figure 2 - Original design of recirculation steam system with DP control

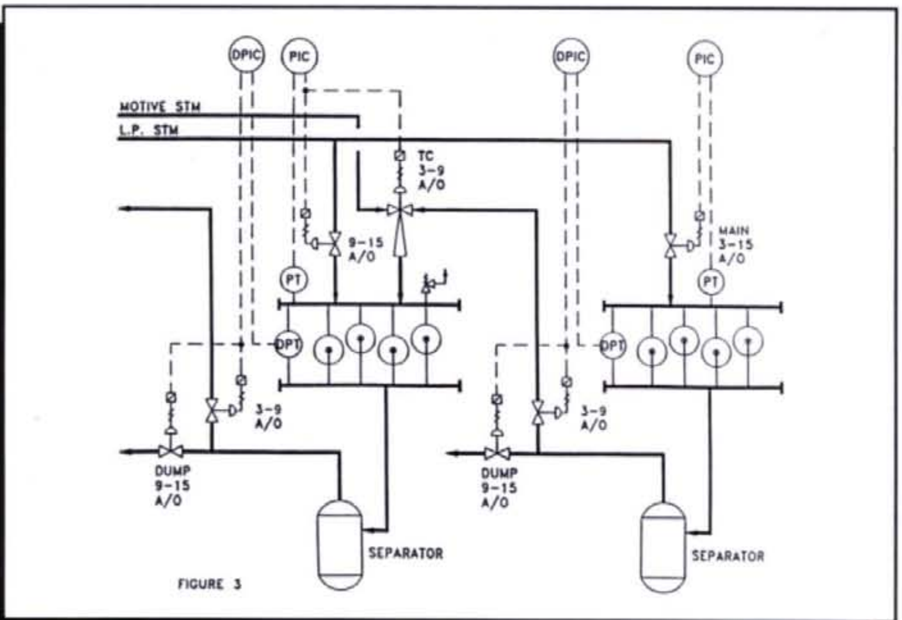

Figure 3 - Thermocompressor-cascade type system

the control range, high control loop gain and cycling, and poor tuning of moisture and pressure control loops. Misapplication and misuse are very common.

The Basic Mechanism

Figure 1, shows the remarkably simple construction of the thermocompressor. Essentially, it is little more than a pipe elbow with a steam nozzle directed down the long leg. In fact, a check valve is required in the inlet approach piping to prevent back flow in case the steam jet is shut off. Important aspects include the location and length of the throat, the length and taper angle of the tail piece, and the shape of the steam nozzle. Motive steam flow is controlled by a tapered needle in the nozzle, effectively a variable orifice rather than a pressure reducing valve. In principle, high pressure steam expands at high velocity through the nozzle, the jet issuing from the nozzle entrains suction steam, accelerating it to high velocity in the throat of the thermocompressor, and the mixture recovers pressure as it decelerates in the tapered tail piece. Thus the energy of high pressure steam is utilized to compress low pressure steam to a higher pressure, i.e., a steam jet compressor.

In practice, the design of a thermocompressor boils down to sizing the throat and motive steam nozzle. The throat size determines the size and other aspects of the body. The throat is normally no larger than about 47% of the discharge pipe bore. In the most efficient mode of operation, the steam jet entrains suction steam at the suction pressure, and the flow volume of the mixture exactly fills the throat. If the steam jet flow is increased further at this point, the volume flow of the mixture becomes greater than can pass through the throat and a reduction in suction flow occurs. This is the effect called "choking", or in control terms "negative gain".

The throat is normally sized to handle the large flow volume at the lowest dryer pressure and the steam nozzle is sized to provide enough energy for the maximum work of compression at the highest dryer pressure. In the latter case the density and velocity of the steam are at a maximum, such that the flow volume does not fill the throat. Accordingly, the flow is subject to turbulent shock loss that reduces performance. Current computer programs account for this shock loss and provide an accurate sizing of the steam nozzle, but earlier designs oversized the nozzles by as much as 100%. Oversized nozzles brought on high gain in control loops and other problems to say nothing about a need for larger safety relief valves.

Operating Characteristics

A common misapprehension about motive steam requirements is that by using lower motive steam pressure, the mill will save energy. The theory is that if motive steam is extracted at 125 lb. instead of 300 lb., the difference will automatically be converted into more generated power. Of course, this assumption is incorrect. In a typical case with dryers operating in the range of 50 lb., the consumption of 300 lb. is about 40% less and the net energy cost to the mill is less, or at worst a standoff, as compared to using 125 lb. motive steam.

In the worst cases the motive steam pressure is little more than 50% higher than the dryer steam pressure. At this level, motive steam required rises to more than double the amount of steam being recirculated, and it may exceed the amount needed by the dryer section, resulting in major steam losses and difficulty in controlling pressures.

Some managers fear that superheat in the motive steam will inhibit drying or dry up steam joint seals. The fact is that even starting with high levels of superheat, the conversion of energy to the work of compression results in supersaturation in the throat (it's wet), and this stuff mixes with recirculated steam that has two or three percent carryover condensate (hopefully not more). The discharge after recompression rarely has more than 10 degrees superheat.

A separator is a separator, or is it? Normally, a 6" or 8" pipe dumps blow-through steam carrying three or four hundred percent condensate in the form of a heavy fog into a separator tank at a velocity of much over 3,000 fpm. The usual outdated separator lacks effective baffles (often eroded out) and the blow-through steam passes right on through without dropping out much of the condensate. From the separator it goes up to the thermocompressor, accelerates to very high velocity in the throat, and discharges back into the dryers. The wet steam erodes the throat of the thermocompressor, increases compression work by adding pipe transport and lift losses to the pressure rise, and impairs compression

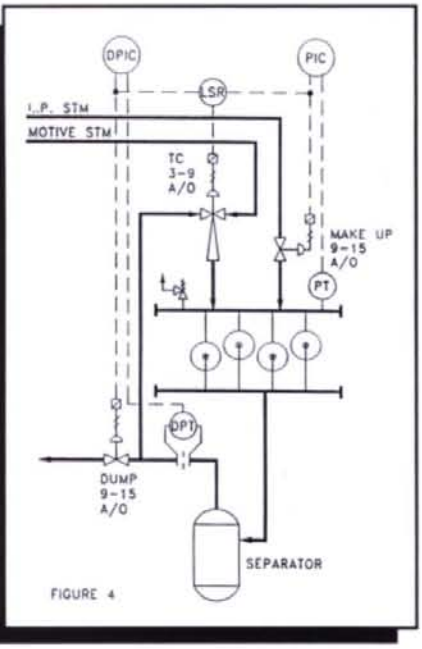

Figure 4 - Thermocompressor recirculation system with Blow-Thru control

efficiency. In addition, Blow-Thru control is questionable since the wet steam increases the DP at the orifice plate by an unreliable amount. No separator is 100% efficient but high separation efficiency is important to thermocompressor operation.

Solving the Application Problem

The original and still common method of controlling dryer drainage with thermocompressors is the recirculation system with DP control illustrated in ***Figure 2***. Ideally, the DPIC (differential pressure controller) modulates the thermocompressor in the lower half range of its output signal. If after opening wide, the thermocompressor fails to raise the DP to setpoint, the signal continues to rise, opening the dump valve (to waste) in the upper half range. In the event of overpressure in the dryers, the LSR (low signal selector relay) allows the PIC (pressure controller) to throttle the thermocompressor after first closing the makeup valve.

The original system is fundamentally defective because it cannot cope with wide changes in condensing load. If properly designed to handle the max condensing load at max pressure, the exponential effects of increasing blow-through flow and pipe line pressure losses as pressure and condensing load are reduced soon overload the thermocompressor. This forces the DPIC control to open the dump valve and waste the excess blow-through steam and valuable motive steam along with it. Typically, the system cannot operate below 20 lb. dryer pressure without dumping. The inability to run well at low pressures is a serious handicap in almost all fine paper machines.

In the event of web breaks, the

Table 1

Design Problem	Process Effect	Control Results	Solution
Undersized TC Body & Throat	TC Chokes At Low Pressures & On Web Breaks - Steam Often Dumped To Condenser	DP Gain Negative PC Controls Both DP & Pressure	System Design By Process Simulation
Oversized TC Nozzle	TC Nearly Closed Unstable Dynamics DP Tends To Cycle	Stiction & Backlash High Control Gain	TC Design Program INCL Dynamic Loss
Quick Opening Spindle	Controls Oscillate	Very High Gain In DP Control - Cycling	Equal Percentage Valve Characteristic
Low Motive Steam Pressure	TC Wide Open Not Able To Control Dumps Steam On Run	PIC Controls TC & Makeup Valve High DPIC Output	Raise Motive Pressure
Dryer DP Control Of Dryer Drainage	TC Chokes At Low Pressure & Breaks And Dumps Steam Unresponsive To Load Surges	Frequent Switching DC To PC W/Deadband Optimum Setpoint A Problem	Blow-Thru Controls
Inefficient Condensate Separator	Reduces TC Efficiency Erodes TC Throat Increases DP & Work	Errors In Orifice Flow Measurement - Process Control Non-Linear	Radial Type Separators
Piping & Dryer Syphons Over Or Undersized	TC Wide Open Dryer Flooding Dumps Steam On Run	PIC Controls TC & Makeup Valve High DPIC Output	System Design By Process Simulation

flow of blow-through steam tends to double because it is not much impeded by condensate in the syphons. The pipe line losses increase with the square of the flow, the two effects grossly overloading the thermocompressor and forcing the DPIC to dump most of the excess blow-through steam to the condenser. Massive dumping from all steam sections on breaks overloads the condenser and vacuum system and usually results in flooded dryers.

The thermocompressor-cascade system shown in ***Figure 3*** should have been discarded at conception, but some are still in operation. The thermocompressor entrains the blow-through steam from a primary section and blows it into a secondary section. The thermocompressor is normally wide open and valuable motive steam is wasted at all but one ideal point. Extra work is always needed because of the pressure drop in the DP valve, and if the pressure in the primary section is lowered below the secondary pressure, the work increases exponentially, quickly exceeding the capacity of the thermocompressor. At low pressures and on breaks this system behaves quite like the original DP control system, dumping steam to waste.

Blow-Thru control and the thermocompressor are an outstanding natural team. The system configuration shown in ***Figure 4*** is identical to the original recirculation system except that DP control is maintained across an orifice plate in the blow-through line instead of between dryer inlet and outlet headers. Caution is necessary here to distinguish between this method and Flow control. As defined here, Blow-Thru control is control of the velocity head of the blow-through steam, the method developed through fundamental analysis of the process. Flow control, the untrustworthy imitation of Blow-Thru control, has no basis in the process mechanics and has proven unworkable.

The range of action required of the thermocompressor is greatly reduced under Blow-Thru control. The flow of blow-through steam automatically varies with steam pressure (varies as the square root of density) and the condensing rate in the dryer section inherently varies identically. Blow-through flow is therefore a fixed percentage of the condensing rate

The flow and the DP are a maximum at the maximum dryer pressure. The key effect, however, is that the flow and dryer DP drop to a minimum at the lowest dryer pressure. The size of the thermocompressor throat required is thus relatively small despite the great increase in the specific volume of the steam. In a recent case, dryer operating pressures as low as 3.0 psi vacuum have worked well with thermocompressors recycling the blow-through steam in the normal way.

The ability of Blow-Thru control to prevent steam loss on web breaks is generally well known but other technical benefits are also obtained. The dryer DP drops by roughly 70% on a break, which is in accordance with the process mechanics when blow-through flow is restrained at a steady rate. The compression work is thus reduced at that time and the controller reduces the signal to the thermocompressor accordingly. The thermocompressor remains in normal control range in this case as well as in all other points of normal steaming load. Not only is the thermocompressor always in its working range at all operating conditions but a single semi-permanent Blow-Thru control setting may be used. This is in great contrast to DP control in which compression work increases exponentially as dryer pressure is reduced or on load loss during breaks and the thermocompressor chokes with the nozzle wide open.

The productive use of thermocompressors involves the solution of several process and control problems. ***Table 1*** summarizes the design problems, the consequences, and the required design improvements. In addition to the factors already mentioned, the table includes process simulation as a necessary part of sizing not only of thermocompressors but of whole dryer drainage systems.

There is simply no other reasonable way to take into account so many complex factors involved in the drying process, such as the various flows and condensing rates and the pressure losses in two phase flow due to both pipe friction and centrifugal force in the dryers. It is a simple truism that all the individual parts, especially the thermocompressors, must perform flawlessly well at every condition of dryer operation to maintain a high level of paper machine efficiency. ■

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