PROCESS CONTROL CONSIDERATIONS FOR LARGE AMMONIA PLANTS

Additional controls and instrumentation can add to a plant's performance but it will not be low-cost protection.

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Recently a feature article cited problems experienced by several of the new large ammonia plants. In several cases the various problems caused a loss of production ranging up to \$7.5 million. The article made it clear that the size of new ammonia plants has guaranteed that any startup delays or breakdowns would be expensive.(1)

A variety of reasons were cited for the difficulties, including pinching pennies for spare parts, careless construction and maintenance work, and a lack of skilled operators. Also emphasized as a contributing factor is cost cutting on plant controls; it was stated that "many plant owners have been satisfied with a bare minimum of boiler controls, water level indicators, and temperature instrumentation—all vitally necessary to keep a plant running smoothly."

It was written by a reporter who, as a representative of one of our outstanding business publications, had the opportunity to discuss this matter with a good number of well-informed people in the ammonia business. The conclusions drawn in regard to the underlying causes of the ammonia plant difficulties merit our serious consideration. This article will present some comments on the matter of the extent and adequacy of controls on the new ammonia plants.

The single-train concept

Most of the new ammonia plants employ the single-train concept. This design, as applied to the large capacity plants, has made many of the older multi-train plants economically obsolete. On the other hand, the single-train plant has an inherent weakness,—that is,failure in a single component, the "weak link" so to speak, may cause a failure of the entire plant.

It is for this reason that no plant is truly "single train". The object thus is to identify the critical elements and reinforce them. Spares are provided in many instances, as for example in boiler feed pumps, MEA pumps, standby turbo-generators and several other instances. The general rule can be stated that if a particular item is a machine, involving rather complex moving parts, and if the installed cost of a spare is reasonable, then most probably the cost of the spare is justified as good insurance. Therefore, to some extent, most new large-scale plants are, in fact, to some degree multi-train plants.

Consider now a typical control circuit. The set of components of almost any automatic control circuit fits the criteria of a complex mechanical device, and the cost of a spare control circuit is a reasonable figure. Why then are not plants equipped with spare control circuits?

To some extent, of course, spare instrumentation is provided. For example, check thermocouples are installed where deemed advisable, various over-rides are provided on controllers and cascade control systems, and alarms and trips are installed in many circuits. Actually, however, this degree of sparing is minimal—control circuits in general are not spared.

This practice is not a matter of economy. If spare controllers could serve the same purpose as spare boiler feed pumps, it is certain that designers and the industry would provide them for critical service. This is not a matter of penny-pinching, but a matter of a need for a new technology. A spare pump is put into operation when a signal is received, via the instrumentation circuit, that the spare is needed. To apply this technique to control circuits requires a control system which can recognize a failure within itself, and which can distinguish between true and false signals.

Present "state of the art" instrumentation can do the job but a prohibitive maintenance and training effort would be required by the user. The system, of course, would be much more complex (i.e. multiple logic circuits). An attempt to achieve a higher degree of reliability through duplication with present "state of the art" hardware would be largely self-defeating. The multiplicity of hardware, with the associated logic, would present an operational and maintenance horror.

Use of computer control

Present day computer technology, particularly in the realm of direct digital control, or DDC, can begin to approach this problem. The computer could, to take a particularly simple example, undertake the lean solvent flow control task. It can determine the behavior of the transmitter, the reasonableness of the measurement, high or low measurement alarm limits, measurement compensation, set point limits, deviation limits, control behavior, determine restricted valve output, filter circuit, and fluid dynamics noises. At the same time it could recognize the possibility of instrument tubing failure, pump instability or failure, pipe line plugging or rupture, exchanger bypassing and leakage, and a host of similar parameters in this loop. This logic in turn would provide output logic patterns through calculation of this system and adjust related unit operations accordingly.

This is possible today and represents an order of magnitude better plant control. Its cost, both soft ware and hardware are considered prohibitive today by most industrial management.

Control circuits must remain, for the present, as conventional single-train items in single-train plants. The designer must therefore anticipate instrumentation failures and attempt to soften the blow of such failure by consideration of "fail-safe" philosophy. The peculiar problems facing the systems engineer concerned with the design of control systems for "energy balanced" ammonia plants has been well stated by E. N. Martin of Imperial Chemical Industries:

"The most important point is that, in the interest of efficiency, every scrap of available heat is recovered, much of it used in raising steam to satisfy both process and power requirements. This results in tight, and sometimes regenerative, coupling between different sections of the plant so that disturbances can be propagated very quickly with little attenuation. The speed of reaction is also enhanced, of course, because, in reducing capital cost, vessel volumes and hence process time constants are minimized. This, in turn, emphasized the need for high performance control and trip systems if the plant is to be kept in steady operation and, together with the change of scale which implies that the number of control loops is small in relation to the plant output, magnifies their relative importance."

Design of fail-safe plants

In its simplest form the "fail safe" philosophy requires the proper choice of the least hazardous valve action in event of

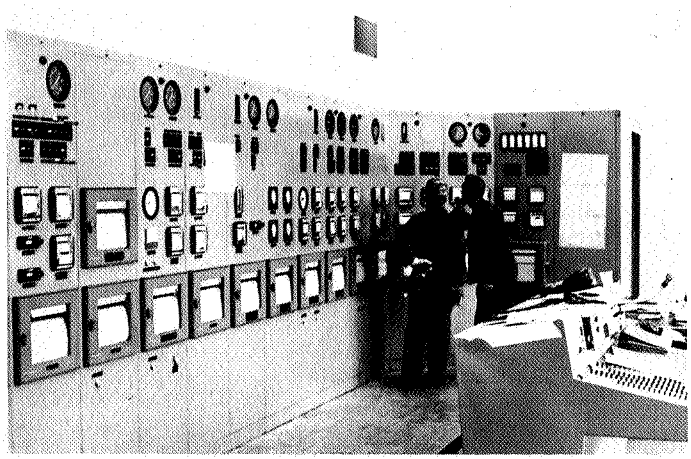

Figure 1. Control Room for 1,000 ton-a-day ammonia plant of Ammoniak Unie. N.V., located at Pernis, The Netherlands.

instrument air failure. It involves addition of alarm and trip circuits; it sometimes involves the use of over-ride control circuits.

Frequently, we find that fail-safe design is nothing more than selection of the least hazardous choice of those options which are available. This is not a desirable situation and adds further to the desirability of development of control systems capable of recognizing a failure within itself. Some examples of the type of least hazardous choice the designer is faced with is whether or not to trip a compressor on the basis of vibration monitor signal, or whether to trip a large process furnace on the basis of a flame detector signal.

A recent editorial appearing in *Instrumentation-Technology* commented on the *Wall Street Journal* article and asked why anyone would skimp on the 1-2% represented by instrumentation costs on a plant investment running into many millions of dollars (2). The question is phrased in a somewhat provocative manner. Every design engineer continually makes decisions in which cost is a consideration, usually to be balanced against a subjective estimate of performance, reliability, etc. Very rarely is the choice made deliberately to "skimp" on instrumentation. On the other hand industry generally can tolerate little "gold plating".

In checking several of our own cost records, it is of interest to note that the value of instruments employed in modern am-

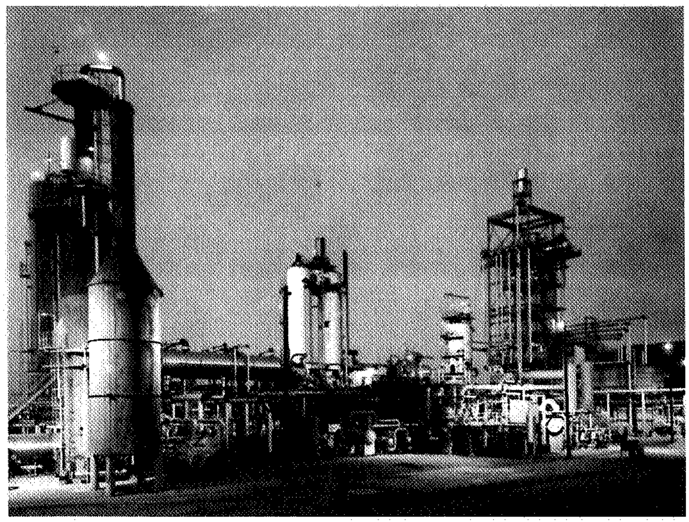

Figure 2. Hill Chemicals' 1,000 ton-a-day ammonia plant at Borger, Texas, is the 23rd large-scale, single-train ammonia plant to be completed by Kellogg since mid-1965.

monia plants is in fact higher than the editors of *Instrumentation-Technology* had thought. For our ammonia plants the instrument cost ranges from about 3 to 4% of material costs. On an erected basis, including the specialized engineering, procurement and construction skills required, the percentage cost is slightly higher. We believe it is unreasonable to conclude that instrumentation failures have been due to cost cutting by engineers;—rather,—we are dealing with complex single-train control circuits for which present—technology—does not enable the designer to specify completely "fail-safe" or completely "spared" components.

Safety related aspects

It is conceivable, through value research in the area of probability anaylsis and statistical techniques, that a more fundamental approach could be made toward identification of the plant weaknesses. At present the approach is essentially

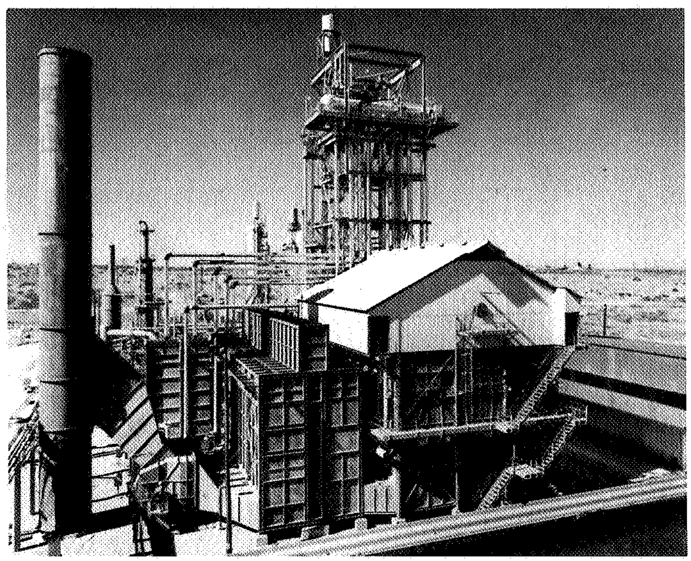

Figure 3. In typical steam reforming section of ammonia plant, rate of flow of feed gas, reforming steam, and air is measured and regulated using flow meters, automatic controllers, and control valves.

a pragmatic blend of the contractors' and clients' experience on previous plants projected into the future, possibly for a modified process, for changed equipment, under changed environmental conditions. Since no single party has a sufficiently wide base to form an adequate statistical sample, this could require a pooled effort to create an operational "zero" defects" program.

Some of the safety-related aspects of control systems in our ammonia plants have been changed in the past few years as the result of experience that has been gained on our new plants. In a paper presented at this safety symposium several years ago (3), the safety aspects of control systems for steam reforming plants were described as we envisioned them at that time.

The following descussion will be concerned not only with a reappraisal of the basic systems, but also with consideration of some of the necessary support systems for safe plant operation. The principal process control systems to be discussed are: (1) Steam-carbon feed control, (2) air-feed control, (3) reformer combustion control, and (4) steam controls.

Although the steam-to-gas ratio is of primary interest, it is not controlled as a primary variable. The relationship derived through a minimum safe operating ratio is policed by a prealarm and trip system. This provides a safe base line for this variable. Practical observation in a number of plants has proven the direct ratio control system to be undesirable.

Use of a ratio control provides a directly manipulated control link between the process reforming system and the primary utility system, the steam system. Plants controlled in this manner have displayed long term sustained forced oscillation through this coupling to the point of instability. The mechanism propagating the disturbance is a regenerative coupling through the waste heat recovery system as previously mentioned by Mr. Martin of ICI.

Controlling steam flow

The activation of the low steam-to-gas ratio trip should employ a direct-acting, rapid,—positive shut-off type of actuator valve combination. In addition, protection against dangerous reverse flows through loss of pumps or compressors must be provided.

The practice of direct air shut-off through loss of feed is carried out as previously reported through a redundantly safe system. The loss of feed immediately triggers electrically an air cut-off system via a quick valve closure. Check valves are also provided to prevent reversals. The action of this shut-off system, or the corollary action of a compressor trip or line blockage can produce a major plant upset.

Emergency supplementary steam is provided, usually by means of an auxiliary boiler, to reduce the severity on operating heat transfer equipment but the direct result is the loss of a large block of steam production. Automatic controls are, of course, provided to increase supplementary generation to a maximum. This is sometimes insufficient as control turndown considerations limit the amount available immediately from standby equipment. Panel mounted controls and emergency trip switches allow regulation of large steam users to provide rapid adjustment toward a balance.

Firing controls

Firing controls have not been extensively modified. In general, automatic reformer fuel cutoff is avoided. This is largely based on the need for avoiding thermal shocks coupled with a plant-wide emergency shutdown. Additional care must be taken in monitoring the various firing conditions, such as fuel characteristics and supplies, air supplies, and draft conditions. The emphasis continues on the indirect variables inasmuch as direct flame monitoring equipment continues to be unreliable.

Main panel mounted fuel pressure controls with conventional alarm switch constraints are in general sufficient supply monitors. Material characteristics are implied through gas feed meters and/or specific gravity analysis. Independent limiting pressure controllers and burner valve "limit stops" maintain full burner capacity flow. Pressure records are used on variable firing burners to help assure combustion under safe conditions.

The heart of safe firing controls lies in the draft control system. The induced draft fan with either speed control or damper control is augmented by an automatically actuated steam ring to assure safe conditions over a short time span to allow operator reaction time.

In cases where furnace dampers are provided, great care must be exercised to insure fail-safe action, i.e., open damper under the aerodynamic contitions in the duct. Attention to detail is essential in that loose linkages, binding bearing surfaces, warpage of blade control surfaces and mechanical components, insufficient operational forces, inadequate air supply and improper limit stops can act to reduce or eliminate the "fail safe" mechanism employed with resulting hazardous effects.

Achieving steam control

The stabilization of supplementary steam generators having a high firing rate has been achieved through the use of feed forward control loops linking the combustion and draft controls.

The plant water inventory, and hence the steam drum level control, is necessary to transfer the process heat safely. To insure dynamic stability a holding time of 2 to 3 min. is employed.—an additional margin of safety is provided by storage in the deaerator and water treating facility. Automatic boiler feed water pump start-up is always provided. A standard type of three element control system is utilized. In addition to the normal code specified level requirements, a television monitoring system provides the control panel operator with a high degree of confidence in his conventional instrument record. Independent switch actuated alarms and reserve air supplies are provided as backup for this control system.

Also fundamental in the boiler water level controls design is the requirement of stable forced or thermosiphon circulation through the generator units. Careful system design of elevations, piping components, heat exchangers and drum internals provides a degree of safety in design. Continuous recording of system operational densities and differential pressures provides a check against poorly operated systems that could result in plant upsets and possibly failures.

It is difficult, and certainly uneconomic, to design a boiler level system to accommodate and smooth slug flow requirements. Present designs for high pressure thermosiphon waste heat boilers include instrumentation to indicate that boiler circulation is adequate, and, in addition, special equipment is provided to insure that circulation initiates at startup or can be regained at any hazardous point.

Steam stability

The stability of the steam pressure control system is vital for smooth plant operation. As the plant is totally integrated in waste heat recovery and the storage capability of these systems is relatively small, it is essential to have a rapidly responding pressure control system. In addition, to prevent cascading effects of upsets, trip controls of large blocks of steam are provided as previously indicated.

The rapid response of large governor controlled systems is prevented through desensitized controls to avoid self-propagated steam upsets at the expense of some unnecessary precision in the process control variable. Mechanical trip steam bypass control valves have been found to be relatively unreliable and have been replaced by high response hydraulic control valves.

Destructive vibration at control valve stations, particularly in high pressure steam systems, has led to a change in the detailed design of the stations. It is of interest to note that the current designs can be checked out in advance using a highly sophisticated computer program developed by S. S. Grover of M. W. Kellogg Co. Mr. Grover's work has been published by the ASME. (4) Kellogg will run the computer program, for a nominal cost, for any safety-oriented problem presented by the industry.

All of the comments presented herein relate to the contractor's "standard" ammonia plant. While some clients elect to add additional controls and instrumentation—above the contractor's standard—many others have accepted and operated the standard plant.

While the added marginal instrumentation probably adds to one's peace of mind, it is not clear that plant performance is improved. As we have stated the cost of conventional instrumentation is at least 3% of plant material cost and thus is not a low cost protection of a huge investment, but rather a substantial and reasonable supportive cost. To achieve an increased degree of performance a quantum jump in investment is required for a suitable computer installation. This could eventually lead to implementation of a logical design considering factors of instrument, equipment, and operational nature. Success in the final analysis depends not only on the design concepts, but also on operator understanding and maintenance sympathy, with or without a computer.

Literature cited

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2. Instrumentation Technology, Editorial, (May, 1968).
3. "Design of Fail Safe Control Systems for Steam Reforming Plants," Axelrod and Finneran, Safety in Air and Ammonia Plants, Las Vegas, (Vol. 7).
4. "Analysis of Pressure Pulsations in Reciprocating Compressor Piping Systems," S. S. Grover, ASME Trans., Journal of Engineering for Industry, p. 164-171 (May, 1966).

Discussion

S. STRELZOFF, Chemical Construction Corp.: When Chemico was given the job to design the 1,500 ton/day ammonia plant for Amoco, the client, who had previous experience on a 600 ton ammonia plant, asked for a considerable number of equipment changes and changes in the instrumentation for reasons of safety. The total cost of these changes amounted to more than $2 million. And we believe that this was reasonable.

One of the factors of great importance to new ammonia plants is the overall steam balance. Many new plants, built from scratch, and not attached to any existing production facilities—encounter a serious problem in supplying the steam required for startup operations. Too often no provision is made for it in the new plants. In some instances, the lack of a sufficient supply of steam made the ammonia plant incapable of operating at its 100% designed capacity.

Now this is the thing that the client sometimes does not realize at the time the contract is awarded. But some clients are more sophisticated, as for instance Amoco and the owners of a plant that was built in Holland. I was told by foreign associates of the Dutch company that they themselves actually engineered the whole steam balance because they felt that, in view of the experience of the large ammonia plants, not enough attention was paid to steam requirements during the startup operations.

So I am now asking the question, why with the experience that Kellogg had on ammonia plants do they now add more instrumentation and what sort of increased costs are there as compared to what was originally figured for large ammonia plants? It seems that the experience gained on the previous plants has led to the installation of more and more instrumentation. Are we going to complicate instrumentation to the point that sometimes we have more sophisticated engineering for instrumentation than for the production equipment itself?

FREY: With regard to cost, we have experienced an increase in instrumentation costs, of course, we have approximately, I would say, an increase of approximately 15% due to the increase of instrument prices over the period that we've been in the large ammonia plant business. I would say that we've added approximately another 10% to the cost by modifying basic instrumentation. However, there have not been significant additions to the scope of instrumentation. We have not added substantially to the cost of our instrumentation over those two factors, which one of the points that we have made in the paper.

I would like to ask a question in return. Did I hear correctly that on the 1,500 ton plant you added $2 million over and above the previous concept of instrumentation?

STRELZOFF: No, it's just the cost in the change of the instrumentation. There were many other things omitted in the previous plant, the list of which I do not remember.

FREY: What type of items are you referring to, instrumentation or equipment related items?

STRELZOFF: I cannot mention all the items.

FINNERAN: Using a figure of 4% for instrumentation, that two million dollars would, of course, correspond to a $50 million dollar plant, which is out of the order of magnitude for this type plant. What sort of plant were you speaking of?

STRELZOFF: I am not prepared to say more than the figures that I just mentioned. The fact is this, that the client himself, after accepting the original proposal, stayed away for three weeks. He evaluated all the problems they had apparently encountered in a large single train plant, mentioned these problems and asked what we could do about them. Finally we agreed to a list of changes and modifications which did not necessarily cover only instrumentation. I told you that the steam balance was mentioned as one of the problems. That meant perhaps that a larger boiler capacity would be required. The total cost amounted to, I would say, more than $2-1/2 Million.

E. WELLS, American Oil Co., Texas City, Tex.: Mr. Strelzoff's comments imply that the magnitude of changes we requested Chemico to make in their proposal for our 1,500 ton plant have some relationship to the number of deficiencies in our earlier 600 ton plant. This is not correct. We did not review the earlier plant performance with Chemico, and the changes relate only to the Chemico proposal.

I don't think this meeting is the proper place to compare performance of competitive contractors plants, but I will say that we have been quite happy with the performance of our 600 ton unit. It was the pioneer of the large single train plants, and it has performed better than many more recent ones. Incidentally, we like to take about as much credit for that as the contractors.

Q. The speaker mentioned that the direct ratio control between steam and gas would cycle. I wonder why ratio controllers would cycle in such a case and not in some other case I know of.

FREY: Well, we do not understand the exact theorectical coupling on this, so we can't discuss it directly from a theoretical or mathematical basis. We have seen it in a plant, and also one of our clients reported it in his plant. Of course the paper also indicated that this was a direct function of the degree of integration in the design of the waste heat recovery system which is the regenerative mechanism.

STRELZOFF: My comment is addressed to Mr. Wells. It is true what you said. True that a great deal of credit belongs to Amoco. But I mention that the list was presented by Amoco for changes and modifications, and not necessarily by Chemico. And the changes were probably just as well—the concept maybe Chemico had, but that's the point, gentlemen. To some extent, engineer/contractors, in a competitive business, certainly have to make proposals under pressure and make the price as low as possible. It's very remarkable on Amoco's part to come up with a list of things they wanted to have changed and that they were prepared to pay for these changes.

Q. In your test you mention that under natural total plant shutdown, you would not shut off the firing to the furnace in order to avoid thermal shocks. Am I mistaken in that?

FREY: No, that's correct. That's what the paper said.

Q. Would not gross overfiring of the furnace be significant and almost be disaster in that case?

FREY: We leave this up to the operator at shutdown. If you have a complete feed system failure or cutoff you will down the furnace. We try to avoid doing this by instrumentation to avoid the rather common instrumentation failure shutdowns, not associated with the feed failures and shutdowns.

FINNERAN: Our philosophy in general is to avoid automatic trips or the firing of a furnace. This is not to say that the furnace is not tripped manually. It frequently is, but we tend to recommend that the automatic trip features not be employed. I might add that many plant have them.

Q. You mentioned steam trip valves, that the mechanical types were unreliable. What types of steam trip valves does Kellogg now recommend?

FREY: We have a hydraulic trip system at present which operates off the compressor seal oil system with auxiliary backup. It happens to be a Worthington type valve.

Q. It has a hydraulic operator on a conventional control valve?

FREY: On a conventional control valve, that's correct.

Q. And the type you were referring to was unreliable then is the spring loaded type with the hydraulic.

FREY: Yes.

Q. Action on it? Thank you.

FREY: Yes.

Q. The comment was made about computer control of ammonia plants, and I wonder if the speaker has knowledge or anyone else here would care to comment on any plants operating with computer control at this time.

FREY: There are several plants operating with computer control at present but our clients have not disclosed the exact nature of this computer control.