Cheng Cycle Development Experience

I. Early Developmental Problems

A. *Turbine Blade Sulfidation*

Problem

Air cooled first stage blades and vanes suffered early failure due to sulfur attack. Sulfur contamination was caused by chemicals carried in injection steam from boiler to engine.

Resolution

The problem was eliminated through a three part solution:

1) improved engine blade and vane coating,
2) improved injection steam purity control,
3) eliminated sulfur compounds in boiler.

Improved Engine Blade and Vane Coating: Sulfur attack of engine blades and vanes is an old problem solved by special coatings on the outside surface of the components. The problem with steam injection in an engine with air cooled components is due to steam mixed with cooling air attacking components from the inside. Allison modified the coating procedure to coat both the outside and inside of the components.

Improved Injection Steam Purity Control: Boiler water chemicals can be carried along with injection steam as droplets. Improved steam moisture control reduces the possibility of chemical carryover with steam.

Eliminated Sulfur Compounds in Boiler: Standard boiler oxygen scavenger contained sulfur. Improved water chemistry eliminated sulfur addition to boiler feedwater.

B. *Superheater Material Selection*

Problem

Traditional materials were originally selected for use in superheater and injection steam piping. Interior metal surfaces form an oxide that is shed as a result of thermal cycling. Oxide particles carried along with injection steam were carried into the engine. Oxide deposits on engine components lead to early failures.

Resolution

Material specifications were changed to use only materials that would not produce oxide. The addition of filters to the steam line insured that no damaging particles would be carried into the engine.

C. Injection Steam Purity

Problem

Water carryover from the boiler and foreign matter in the superheater and injection steam piping led to engine damage. Condensed water in injection steam piping could be carried over into engine during start-up.

Resolution

Improvements in boiler moisture separation and material selection already discussed in the sections above. Special start and stop sequence developed by IPT eliminates the possibility of condensed water in steam piping during plant start-up.

D. Injection Steam Piping

Problem

Aeroderivative engine designs use light-weight material for basic engine construction. The early design of steam piping interface to the engine led to damage of the outer combustor case.

Resolution

Allison strengthened the steam flange connections at the engine. A special design developed by IPT minimizes stress to the engine by external piping. This piping design takes into consideration the need for easy access to engine. Use of this design has eliminated all problems for the engine.

E. Lube Oil Contamination

Problem

Contact between injection steam and the engine lube oil system causes water contamination of oil. Water build-up in the lube oil can lead to lubrication failure for rotating components.

Resolution

Changes to the lube oil system design provide mechanisms that drive water out of the oil. Improved lube oil additives prevent water contamination from causing oil break-down.

F. Engine Surge Margin

Problem

The Allison engine was selected by IPT for Cheng Cycle operation because of large design margins. Steam injection increases compressor pressure ratio, and thereby reduces surge margin. Limits must be placed on engine operation to guarantee that adequate surge margin is maintained. Early attempts at maintaining safe operating conditions created operating problems.

Resolution

Control logic developed by IPT maintains safe engine operating conditions while eliminating problems caused by first designs. This control logic has become standard at all Cheng Cycle plants.

G. Boiler Cold End Design

Problem

High turn down capability of the Cheng Cycle boiler creates a problem in designing the boiler cold end to prevent steaming in the feedwater heater and deaerator. These problems are especially noticeable during plant start-up and shut-down

Resolution

A revised system design eliminates the need for a stack mounted feedwater heater. A regenerative heat exchanger around the deaerator allows increased surface area in the economizer. High efficiency is maintained while eliminating earlier problems.

H. Control Logic

Problem

A key feature of the Cheng Cycle plant is its operating flexibility. Early control logic design did not allow full use of this flexibility.

Resolution

Revised control logic takes into account full plant potential with minimal plant operator action. New logic is now standard in all Cheng Cycle plants.

I. Operating Procedures

Problem

Early plant operations were hindered by unfamiliarity of unique characteristics of Cheng Cycle plant operation and maintenance. Lack of understanding led to reduced plant availability.

Resolution

Improved plant procedures and training resulted in high plant availability.

J. Epicyclic Reduction Gear

Problem

Manufacturing problems with epicyclic reduction gear-sets resulted in vibration induced failures of engines.

Resolution

Improvements in gear manufacturing quality control have reduced problems. Increased monitoring helps identify problems before serious damage occurs. Epicyclic design not recommended for new installations.

II. On-going Development

A. Engine Rating

Problem

Many customers look for more power from the same basic engine design. Overly aggressive engine performance guarantees lead to engine operating conditions that result in unacceptable durability.

Resolution

On-going efforts by IPT and its licensees have led to the use of improved engine components that have improved durability. Development of an up-rated engine based on 501-KB5S hardware for new plants will result in higher output with engine lifetimes comparable to existing plants. Temporary measures by Allison to reduce steam injected engine firing temperature will ensure that engine durability is verified before next performance increase.

B. Engine Lifetime Improvements

Problem

With standard engine ratings, time between major overhauls are in the 35,000 hour range. Increased engine performance is needed with no decrease in lifetime.

Resolution

Several programs under way with engine manufacturer. Improvements in component design have been introduced in most recent engine configurations. Future developments promise even better performance. IPT continues to perform service evaluation on new engine components to guarantee that Cheng Cycle plants have access to the latest technology as soon as possible.

C. Steam Temperature Control

Problem

Higher engine outputs result in higher steam temperatures at low flow conditions. Market demands cause a shift in emphasis from high generating efficiency to higher overall cycle efficiency. There is a need to maintain plant flexibility while maintaining engine integrity along with high efficiency.

Resolution

IPT has developed a steam temperature control system to provide the high performance of traditional Cheng Cycle, along with the increased flexibility to generate more process steam by controlling steam temperature to the engine.

Development And Operating History Of Cheng Cycle Series 7

The first three units of International Power Technologies' innovative Cheng Cycle Series 7 cogeneration systems (*D&GTW*, April '84) have demonstrated a major step forward in reliability in the two and one-half years these steam-injected gas turbine units have been in service. For the ten month period ending April 1987, IPT says these three Allison 501KS-based systems have averaged better than 95% availability, which the company considers very satisfactory for the new technology. Three other Series 7 units have been installed within the last year and these, too, are also said to be providing reliable service.

Development of the Cheng Cycle technology began in 1974, when Dr. Dah Yu Cheng, a mechanical engineering professor at the University of Santa Clara obtained the first patent on the basic steam-injected gas turbine technology and its application. Dr. Cheng incorporated IPT that same year to actively pursue development and commercialization of his idea.

For several years thereafter, Dr. Cheng and his associates conducted research and development work using small gas turbines. In 1980 a major step occurred towards development of a commercial product when the company began working with the Allison Gas Turbine Div. of General Motors to develop a steam injected version of the 501 industrial gas turbine. Testing of the modified turbine occurred in 1982. Allison designated the production version of this steam-injected turbine the "501KH."

In 1983, the State of California, U.S.A. selected IPT to develop a Series 7 cogeneration project at San Jose State University (SJSU), using the Allison turbine. Also in 1983, IPT reached an agreement with Sunkist Growers, in Ontario, California, U.S.A., to develop a cogeneration project which would employ two Series 7 systems.

IPT has installed three additional Series 7's since the San Jose and Sunkist projects were completed. The following is a summary of all projects to date:

Project	# of Units	Startup Date
SJSU, San Jose, California, U.S.A.	1	December, 1984
Sunkist, Ontario, California, U.S.A	2	January, 1985
Frito-Lay, Bakersfield, California, U.S.A.	1	April, 1986
Hershey Chocolate, Oakdale, California, U.S.A.	1	February, 1987
SRI Int'l, Menlo Park, California, U.S.A.	1	April, 1987

Operating history showing cumulative availability of the IPT San Jose and Sunkist Cheng Cycle Series 7 cogeneration units, equipped with steam injected Allison 501 KH gas turbines. Note the dramatic increasing trend in availability over the past 18 months.

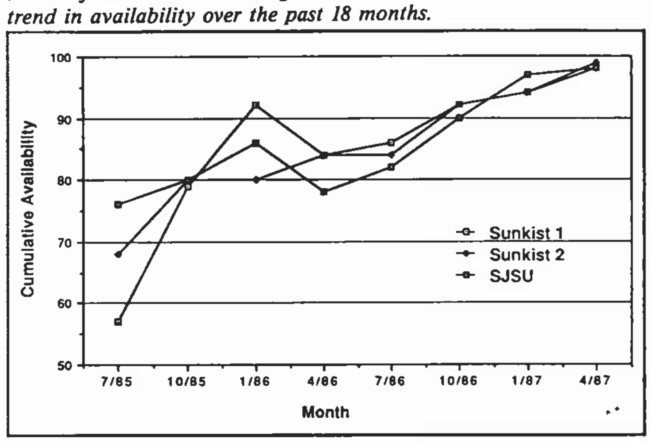
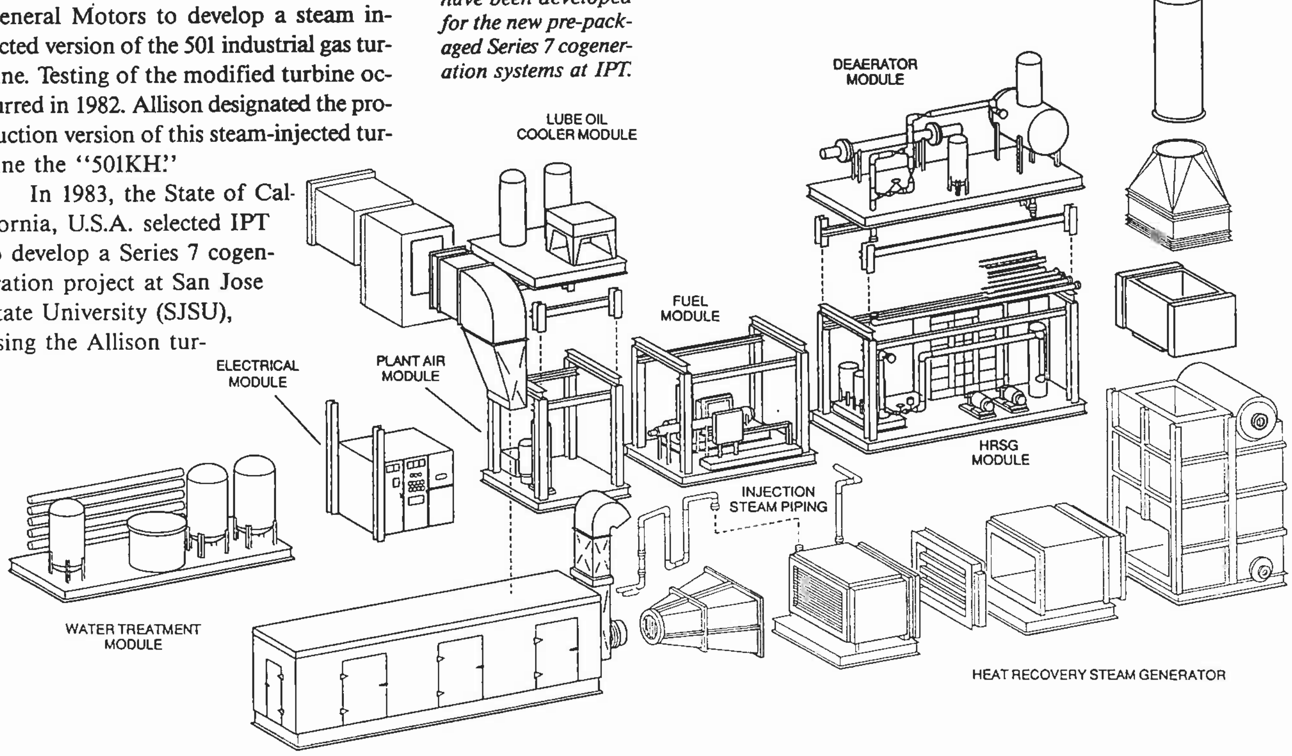
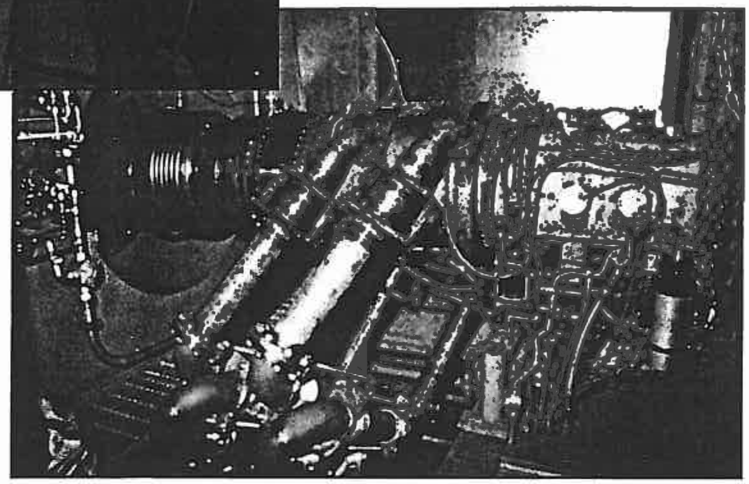


Diagram shows the various modules that have been developed for the new pre-packaged Series 7 cogeneration systems at IPT.



This Cheng Cycle Series 7 cogeneration plant at Sunkist Growers in Ontario, California, U.S.A., was the second of six current Cheng Cycle installations in California.



The new injection steam line design on this Cheng Cycle Allison 501 kH gas turbine is evident in this recent Hershey chocolate installation in Oakdale, California, U.S.A. This design change, along with some other design improvements, have eliminated outer combustor case cracking problems, according to IPT engineers.

The Series 7 has undergone a number of design refinements as a result of IPT's operating experience with the SJSU and Sunkist units. In addition to optimizing the steam injection-related systems, IPT has recently concluded a development effort to enhance the overall reliability and operability of the plant and lower its cost. Modularity and pre-packaging are employed to the optimal level in this new design, and the Series 7 scope has been expanded to include critical balance of plant systems.

The operating histories of the San Jose and Sunkist installations are illustrative of the development process; more so than recent units, which have benefitted from design improvements developed at the first installations. Operating statistics have been provided by IPT's Operations and Maintenance Div. (OMD), which is responsibile for operating and maintaining the SJSU and Sunkist plants. OMD has kept detailed records of plant operations since startup.

A long term measure of a unit's availability, a recent six-month rolling average is illustrated. For each month this is the average of availabilities for that month and the five prior months. All three units have now achieved very good availibility. Six month rolling average availability is now at least 93% for all three units, with the average being 95%.

Although a number of development problems were identified during the first 15 months of operation, the OMD figures demonstrate that they have been addressed and that the Series 7 has matured into a reliable cogeneration system.

The following operating problem conditions were found to be related directly or indirectly to the injection of steam into the turbine: 1. Turbine internal vane and blade cooling passage sulfidation; 2. Compressor surge detector solenoid valve malfunction; 3. Engine over-temperature damage; 4. Turbine lube oil sludging; 5. Super-heater exfoliation; and 6. Turbine labyrinth seal failure.

Typical solutions to some of these problems are listed below to illustrate the extensive development program undertaken to assure good reliability.

In keeping with IPT's stated product development philosophy of incorporating redundant corrections, three remedies were implemented to eliminate sulfidation problems. Allison has added protective coatings to the internal turbine blade and vane passages. IPT has upgraded heat recovery steam generator (HRSG) drum internals to employ a two-stage external steam separator. Control system changes have been incorporated which promote smooth HRSG operation without drum upsets. Since the above improvements were implemented, no further sulfidation problems have been experienced, IPT engineers state.

A joint IPT/Allison review determined that the compressor surge detector solenoid valve, which is not used in other Allison 501 engines, was not necessary. Thus, the valve has been eliminated. No further problems of this nature have been experienced in any of the IPT operating plants.

On several occasions, combustor cans and turbine blades and vanes suffered damage from over-temperature operation. Now, combustor cans are inspected more frequently in order to reduce the possibility of operating with damaged cans. In addition, IPT is field testing a new combustor can design developed by Allison which will prolong operating life. Engine start sequencing logic and the starter system have also been revised so that light-off occurs consistently at the proper speed.

Upon identifying the lube oil sludging problem, IPT reverted to using the ester-based oil originally recommended for this service. Oil/water separation systems have been added to reduce the potential for breakdown of the oil and, based on oil analyses, these systems appear to be performing well. IPT, in conjunction with Allison and a major lube oil supplier, has developed an alternative oil that is not as sensitive to breakdown or sludging and will be performing field tests soon.

In order to eliminate superheater exfoliation or rust-related problems, superheaters at San Jose and Sunkist were internally nickel plated on site. Superheaters at other installations employ either Alonized or stainless tubing. No further exfoliation problems have been experienced as a result.

Improved alignment procedures and engine mounts have been implemented to prevent turbine labyrinth seal failure, and steam injection piping has been redesigned to reduce lateral loads. IPT reports that no seal failures have occurred since these solutions were implemented.

Based on its experience with the SJSU and Sunkist installations, IPT's design, scope of supply, and manufacturing strategy have undergone significant refinements. IPT's current product design philosophy emphasizes five principles:

1. Systematic incorporation of operating feedback into plant design. In this respect, IPT is in the enviable position of being both a supplier and an operator of several Cheng Cycle plants. As a result, operating feedback is routine and can be incorporated into plant designs over a long period of time.

2. Product design standardization to the maximum extent feasible. This approach allows each new plant to rely on lessons learned from previous similar installations. Thus, increasing operability and reliability.

3. A design that is biased toward shop fabrication, rather than field fabrication, IPT says they have found that shop conditions allow for a higher-quality manufacturing/assembly job than can be performed at the construction site.

4. The designation of a single entity responsible for design and procurement of all major systems. In operating its first installations, IPT found that the use of a variety of unrelated vendors was a major source of cogeneration system design and construction problems. To surmount this problem, IPT's scope of supply includes balance of plant equipment normally supplied by others. Thus, the entire cogeneration plant is designed and delivered in an integrated fashion.

5. The development of close, consistent relationships with a limited number of high quality suppliers. In an effort to increase quality and lower costs, IPT has recognized that standardized purchasing, support agreements and designs are needed to deliver a consistently reliable and cost-effective product. Thus in developing its product, IPT says they have emphasized a close working relationship with its suppliers, established on a long-term, rather than just a project-by-project basis.

The SJSU and Sunkist plants represent the first model of the Series 7 commercial product. Later plants (Frito-Lay, Hershey, and SRI) incorporate all changes required to eliminate the development problems experienced at SJSU and Sunkist, plus they use more extensive pre-packaging.

In particular, the bulk of system controls have been integrated into the gen-set skid allowing factory packaging and testing. IPT has recently concluded an effort aimed at maximizing pre-packaging for all systems, and establishing standard designs for balance-of-plant systems such as water and fuel treatment. The new design incorporates all of the five design principles outlined above.

With the IPT's experience to date, they are convinced that the Cheng Cycle has evolved from a theoretical concept in 1974 to a successful, mature cogeneration product in 1987. The development process presented certain challenges which were successfully addressed using redundant solutions. The result is a reliable powerplant, as evidenced by availabilities which are quite satisfactory to IPT, and provide profitable and reliable cogeneration service for them. ★

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