S.S. BADGER ENGINES AND BOILERS

The American Society of Mechanical Engineers

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HISTORIC MECHANICAL ENGINEERING LANDMARK

S.S. BADGER ENGINES AND BOILERS

1952

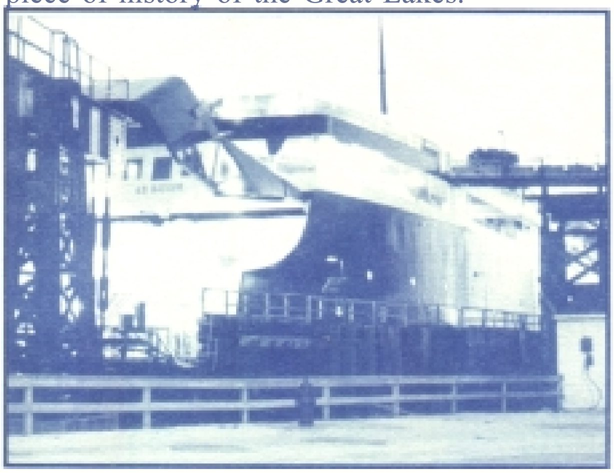
THE TWO 3,500-HP STEEPLE COMPOUND UNAFLOW STEAM ENGINES POWERING THE S.S. BADGER REPRESENT ONE OF THE LAST TYPES OF RECIPROCATING MARINE STEAM ENGINES. BUILT BY THE SKINNER ENGINE COMPANY, MOST UNAFLOW ENGINES ARE SINGLE EXPANSION. THESE FEATURE TANDEM HIGH- AND LOW-PRESSURE CYLINDERS SEPARATED BY A COMMON HEAD. THE BADGER'S FOUR FOSTER-WHEELER TYPE D MARINE BOILERS, WHICH SUPPLY 470-PSIG STEAM TO THE ENGINES, ARE AMONG THE LAST COAL-FIRED MARINE BOILERS BUILT.

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS - 1996

Text of the plaque installed on the S.S. Badger

I. Introduction

The Skinner Compound Unaflow steam engine and Foster-Wheeler coal fired boilers provide a unique propulsion system for a now rare mode of transportation, the steamship. Powering the *S.S.Badger* between Ludington, MI and Manitowoc, WI., the twin four-cylinder engines provide a total of 7000 horsepower for the largest coal fired steamship in the United States. The engineering excellence of the design has endured for over 40 years and has allowed for the renovation of the *Badger,* a treasured piece of history of the Great Lakes.



Loading dock, Ludington

II. History and Development

Car ferry service across Lake Michigan began on Nov. 24, 1892 when the Ann Arbor Railroad launched the *Ann Arbor No. 1* with the first cargo of loaded railroad cars from Frankfort, MI to Kewaunee, WI. Steamships and freighters were not new to the region; the Flint and Pere Marquette Railway had been transporting bulk cargo and passengers across the lake for nearly two decades previous. However, James M. Ashley, president of the Ann Arbor Railroad and former governor of Montana, proved that railroad ferries were a profitable alternative to loose cargo shipping. Cross-lake shipping changed thereafter. The Flint and Pere Marquette soon contracted naval architect Robert Logan to design the first steel hulled cross-lake car ferry, the *Pere Marquette,* which became the standard for many railroad ferries built in the 20th century. In a little over a decade, three competing rail lines, the Ann Arbor, the Flint and Pere Marquette, and the Grand Trunk line, were utilizing 11 car ferries, most with passenger service. The Flint and Pere Marquette sold their break bulk fleet, as it had become obsolete.

The years after the turn of the century were very successful for ferries, with expanding service to more cities. This growth continued through the depression era, interrupted only by World War I, in which the United States government established the United States Railroad Association to run the railroads and, in turn, the Lake Michigan Car Ferry Association, which pooled the fleets of the Ann Arbor, Grand Trunk, and Pere Marquette to aid the war effort.

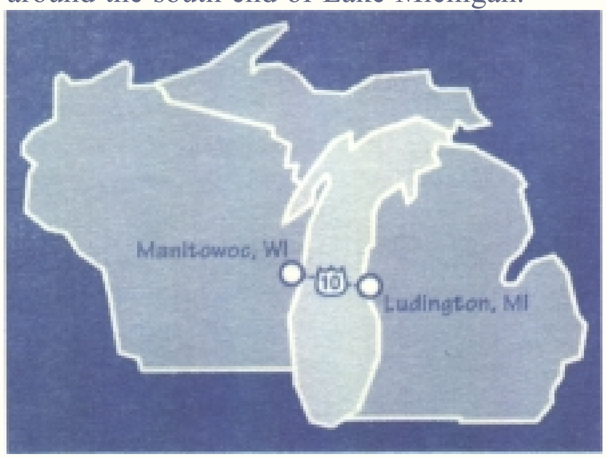
The 1920's saw production of more and better ferries with triple expansion engines and Scotch marine boilers. Speeds reached 14mph for the first time.

The Great Depression forced the downsizing of the fleets, due to decreased commerce. The oldest ships were either sold or scrapped. However, as auto and passenger traffic began to increase, some ferries were remodeled with more autodecks and amenities to accommodate these trends.

The Pere Marquette *City of Midland* was the first to feature Skinner Unaflow engines, two passenger decks, and an autodeck above the rail car deck. It proved to be very successful, and only World War II prevented the Pere Marquette from building a sister.

The post-war era through the middle 1950's proved to be the biggest years for Lake Michigan ferries. The increased commerce from tremendous economic growth required more routes, faster travel, and better service. The final additions to the Ludington fleet helped fulfill these needs. The Chesapeake and Ohio Railroad, which had purchased the Pere Marquette, added the "twin Queens of the Lakes", the *S.S.Badger* and the *S.S.Spartan,* in 1952. Built at a cost of $5 million each, both were powered by Skinner Compound Unaflow engines and Foster-Wheeler boilers and could reach a speed of 18mph. They were the largest Great Lakes rail car ferries ever built. The Skinner Unaflow engines performed so well, that other ships in the fleet were retrofited with Skinner engines.

By the end of the 1960's, however, the railroads again began to downsize their fleets. Improved switching techniques in the Chicago area allowed for trains to more easily make their way through the city and around the south end of Lake Michigan.



Maritime map of ferry route

It quickly became more economical to travel around the lake at upwards of 50mph than over it at 18mph. The development of the interstate highway system and the subsequent growth of the trucking industry put further strain on the railroads. The railroads also cited vessel upkeep and increasing labor and fuel costs as reasons for abandoning their fleets. Service tapered through the late 1970's until the C & O sold their fleet in 1983 to the Michigan-Wisconsin Transportation Company, which ceased operations in 1990. Lake Michigan was without car ferries until the summer of 1992.

III. System Description

The *S.S. Badger* was built by the Christy Corporation of Sturgeon Bay, WI., for the C&O Railroad. Launched on Sept. 6, 1952, she began regular service on March 21, 1953. At the time, the *Badger* and her sister ship the *Spartan* were the largest car ferries in service on the Great Lakes. The *Badger* continues to hold this distinction of the largest coal fired steam driven ferry on the Great Lakes and, in fact, the largest such vessel in the United States. The *Badger* and the *Spartan* were also the first vessels to be powered by a new type of Unaflow engine introduced by the Skinner Engine Company in 1950.

The Steeple Compound Unaflow design took advantage of the Woolf Cycle, and while this thermodynamic cycle was not new to marine applications, the Skinner Company introduced many innovative design features in this engine. The *Badger* is powered by two of these Skinner Steeple Compound Unaflow steam engines, each with four cylinders. Each engine is rated at 3500 SHP at 118 rpm to give a total of 7000 SHP, which drives the *Badger* across Lake Michigan at a maximum speed of 24 mph; the usual average speed is around 18 mph with running rpm from 50 rpm (slow) to 95 rpm (full). Each engine drives a propeller shaft which is roughly 100 ft long and 15 inches in diameter. The propellers are made of cast steel with four blades and a 13 ft 10 inch diameter. The steam is supplied to the engines by four coal fired Foster-Wheeler type "D" marine boilers.

IV. The Skinner Unaflow Steam Engine

The Skinner Marine Unaflow steam engine was introduced in 1929 by the Skinner Engine Company of Erie, PA. Called "Unaflow" engines because of the unidirectional path of the steam through the cylinders, the engine quickly became the logical choice for many ships because of outstanding economy, reliability, maneuverability and low maintenance.

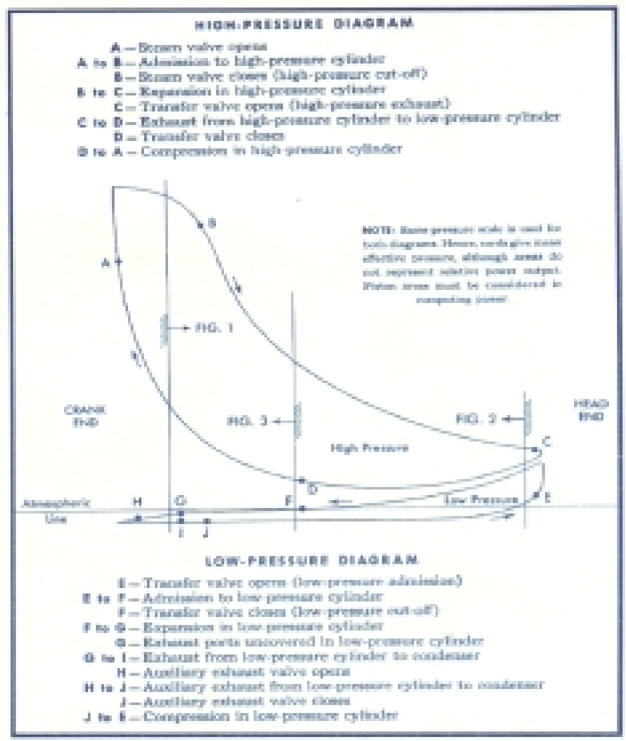
The Unaflow engines on the *Badger* are a compound steeple reciprocating design with four piston rods driving each engine crankshaft.

Piston

Compound engines - engines with more than one expansion stage for the steam - were developed to take advantage of higher efficiency, higher pressure boilers. In the design used on the *Badger,* there are two expansion stages through two cylinders using a single piston rod. The high pressure cylinder with a 22.5 inch diameter piston is mounted directly above a low pressure cylinder with a 55 inch diameter piston, giving the arrangement the appearance of a church steeple, hence, the "steeple" design. The two pistons are rigidly attached to a single piston rod which completes a 26 inch stroke in each cycle. A cut away view of this arrangement is shown on the next two pages.

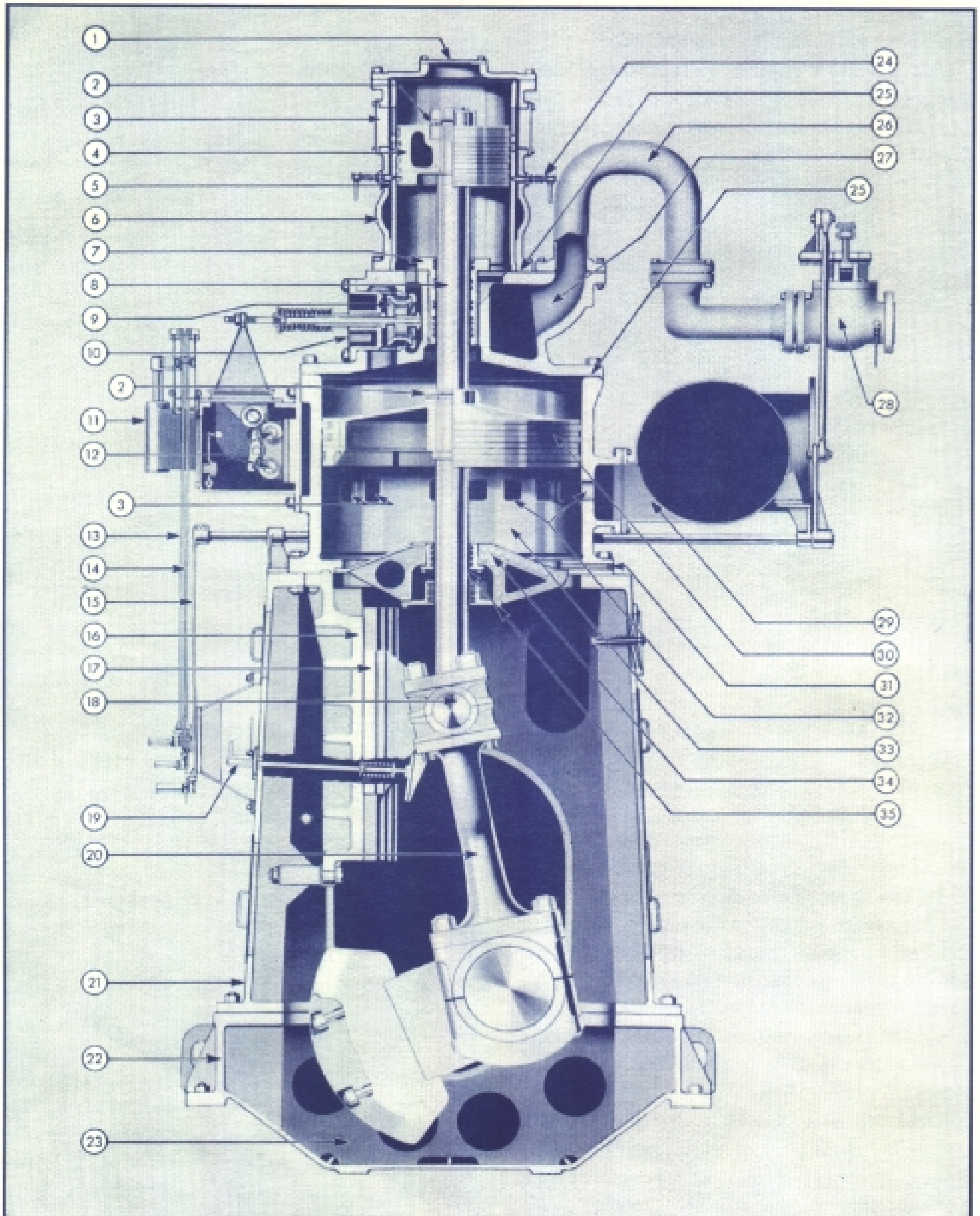
V. <u>Cycle Sequence</u>

A single cylinder head serves both cylinders, supplying high pressure steam to the upper cylinder. The diagram below shows the cycle which begins when both pistons are near bottom dead center.



Woolf Cycle Diagram

High pressure, superheated steam enters below the high pressure piston and forces it up. The larger low pressure piston, of course follows since it is rigidly attached through the piston rod. Soon after the pistons begin to move up, the steam valve closes and the steam continues to expand forcing the pistons to top dead center. Near top dead center, the transfer valve opens, and the steam enters the low pressure cylinder, forcing it to move down. Expanded (therefore cooled) steam also enters the annulus around the high pressure cylinder, acting to cool it and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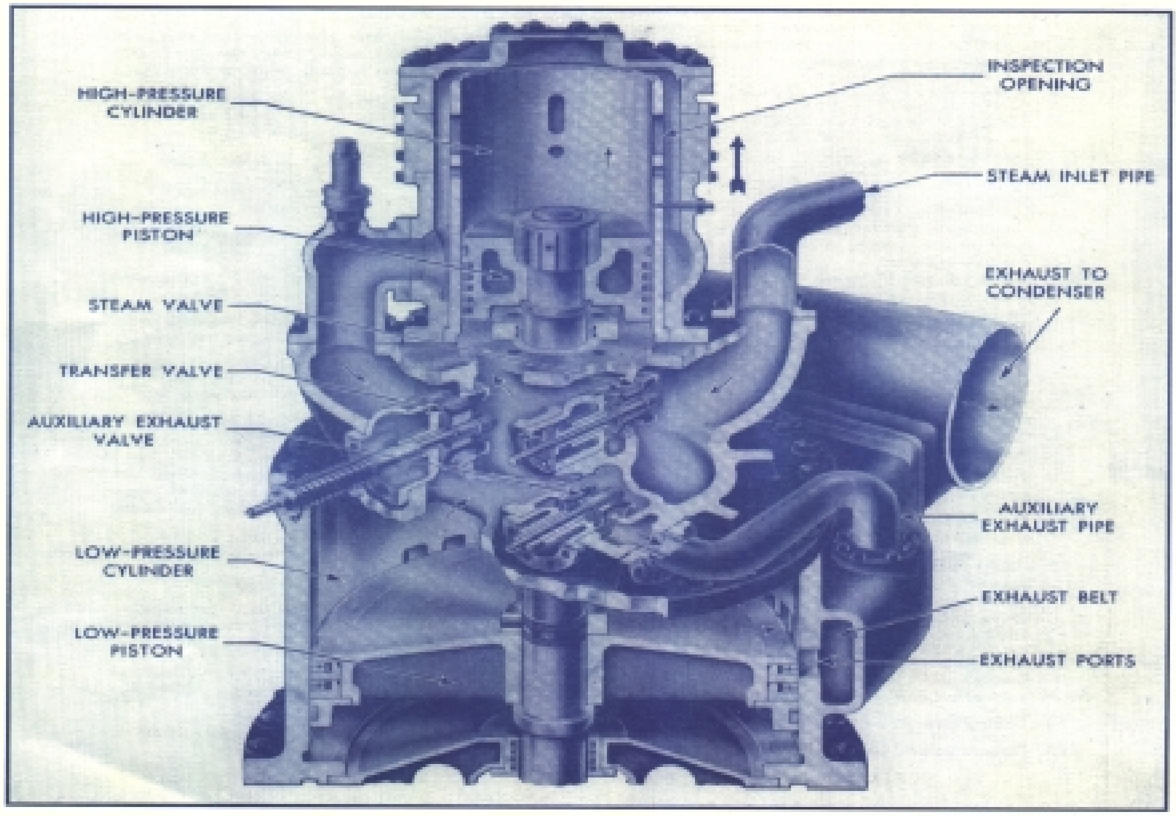
DESIGN FEATURES OF THE SKINNER COMPOUND UNAFLOW MARINE STEAM ENGINE

1. *Inspection cover.*
2. *Positive piston rod lock.*
3. *Four inspection parts for piston rings.*
4. *High-pressure piston, alloy iron.*
5. *High-pressure cylinder liner, forged steel, chromium platted. Taper bored to compensate for expansion due to temperature gradient. Cooled by low-pressure steam.*
6. *High-pressure cylinder casing, alloy iron.*
7. *High-pressure piston rod steam packing with special bronze rings. Cooled by low-pressure steam.*
8. *Piston rod, forged alloy steel, ground to fine finish.*
9. *Steam-tight transfer valve, transfers steam to low-pressure cylinder after expansion in high-pressure cylinder. Steum valve (not shown) admits steam to high-pressure cylinder from manifold. Auxiliary exhaust valve (not shown), relieves compression in low-pressure cylinder when reversing, and may be held open to permit removal of water from self-draining high-pressure cylinder and head. All valves are steam-tight, double-seat, telescopic poppet type, with free seat. Permanently tight, regardless of variation in pressure and temperature.*
10. *Valve cage, steel, with integral seats. All valves mounted in cages for convenience in handling.*
11. *Return motion mechanism, hydraulic controls, for lead and cut-off.*
12. *Dual camshafts for accurate timing and positive control of lead and cut-off. All cams, rollers and gears are hardened and ground to close tolerances. Rollers have line contact on cams. Pressure lubrication of all cam mechanism.*
13. *Control lever, cut-off ahead (or lead astern). Control Shifts camshafts hydraulically for minimum effort and quick response.*
14. *Control lever, cut-off astern (or lead astern).*
15. *Throttle valve control lever (hydraulic control).*
16. *Pored crosshead guide, concentrically rabbeted to low-pressure cylinder for permanent alignment.*
17. *Crosshead shoe, rabbitted top and bottom. This construction allows continuous full-load operation either ahead or astern.*
18. *Crosshead and pins, single-piece high-carbon steel forging.*
19. *Permanent indicator reducing motion, with detent, for each cylinder. Permits taking indicator cards at any time without stopping the engine.*
20. *Connecting rod, forged steel, forked at upper end to reduce height, with heat-treated fitted bolts.*
21. *Frame weldment, box type, provides rigidity and total enclosure for cleanliness.*
22. *Base weldment, heavy construction for rigidity.*
23. *Dry sump to prevent oil loss and oxidation due to splash.*
24. *Injectors for steam cylinder oil. Two for each high-pressure cylinder.*
25. *Permanent double ground joints, head to high-pressure and low-pressure cylinders. No gaskets.*
26. *Steam piping, designed to permit expansion.*
27. *Cylinder head, steam-jacketed, cast steel.*
28. *Throttle valve, balanced for ease of operation.*
29. *Exhaust manifold, fabricated steel.*
30. *Low-pressure piston, fabricated steel. Fitted with sectional piston rings and followers with wearband inserts. Rings and followers removable through bulkhead opening.*
31. *Drain for condensate under low-pressure piston.*
32. *Exhaust ports, ample area to manifold.*
33. *Low pressure cylinder, alloy iron, taper bored to compensate for expansion due to temperature gradient.*
34. *Bulkhead, split for removal through crankcase to provide access to low-pressure piston and cylinder.*
35. *Bulkhead and vacuum packing, split cased to facilitate removal.*

TRI-DIMENSIONAL SECTION
(partially diagrammatic)



prevent vaporization of the lubricating oil. About halfway through the stroke, the transfer valve closes, and expansion continues in the low pressure cylinder. Near bottom dead center, exhaust valves open, and steam is exhausted to the condenser. Just before the bottom of the stroke, while steam is leaving the lower cylinder, high pressure steam enters the upper high pressure cylinder and the cycle repeats. Note that this arrangement allows both the "up" and the "down" stroke to be a power stroke.

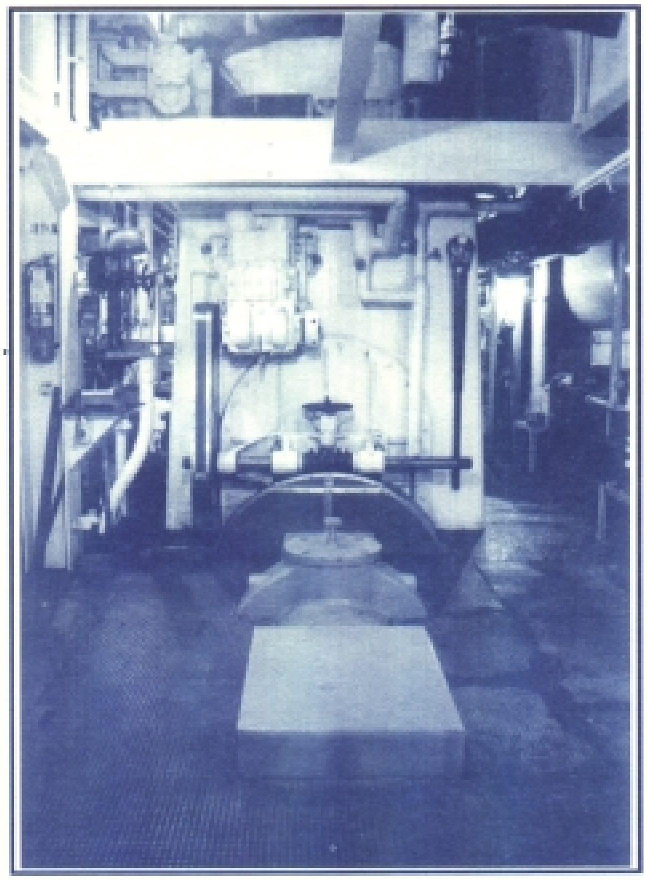
VI. Maintenance Issues

There are two camshafts for each engine which are geared together and driven by a long chain from the crankshaft. The camshafts are mounted on the side of the engine in such a way that they are easily accessible. The cams are very wide (six inches), and the entire camshaft assembly can slide endwise to enable an operator to change cams if necessary.

The high pressure cylinder can be serviced through the top of the engine. One of the innovations of the Skinner design was to make the low pressure cylinders accessible from the interior of the crankcase, after removal of a split lightweight cover. Dismantling the engine to inspect the piston rings, cylinder surface conditions, and lubrication is not necessary because viewports have been built into the engine - enabling operators to view these items at any time.

VII. The Condenser

The steam cycle for this power plant is a closed cycle, meaning that the same water

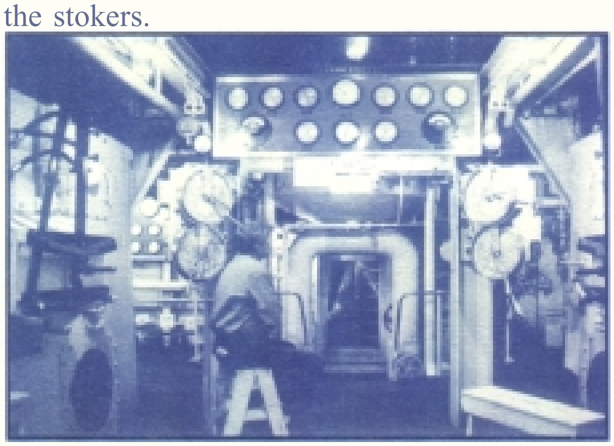


Drive Shaft

circulates through the cycle continuously - from the boiler to the engine to the condenser and pump and back to the boiler. Steam from the low pressure cylinder enters the condenser and begins to condense on the tubes which are cooled by lake water flowing through them and back out to the lake. The pressure in the condenser is dictated by the temperature at which condensing takes place, but it is normally around 27.5 inches of water vacuum pressure.

VIII. Foster-Wheeler Marine Boilers

The *Badger* power plant includes four coal fired marine boilers manufactured by the Foster-Wheeler Company. Each boiler has a total heating surface area of 7675 square feet. The boiler systems include Foster-Wheeler economizers which pre-heat the water going into the boiler using exhaust gasses from the burning of the coal, and Foster-Wheeler superheaters which superheat the steam coming out of the boiler. The boilers are rated at 500 psi and tested to 750 psi. They normally operate at around 470 psi. Superheated steam at 750°F and 470 psi is supplied to the engines at a rate of 29,500 lb/hr. The boilers can supply up to 44,000 lb/hr. Coal is burned in the boilers, and combustion requires both induced draft and forced draft (four large blowers are manually controlled by the crew). The stokers were manufactured by the Hoffman Combustion Engineering Company, and here can be seen one of the few places where modern control technology has been added. Electronic controls have replaced vacuum tube controls to monitor steam pressure in the boiler and control the flow of coal to the boilers through the stokers.



Engine Room

For two daily round trips across the lake, the *Badger* uses an average of 71.2 tons of bituminous coal. The coal is loaded in Manitowoc by large dump trucks. It is no longer necessary to pulverize the coal since it is delivered in a form ready to burn. The pulverization bin is currently used as a holding bin for the coal on its way to the stokers.

The boilers actually provide more steam than is required by the engines. Only three boilers are needed to power the vessel; the fourth is on standby and is fired only to replace a boiler down for repairs. In addition to the propulsion steam engines, the boilers provide steam for several steam turbine engines on board. Two turbine engines are used to drive pumps for the lakewater in the condensers, and two are used to generate the electric power needed on the ferry.

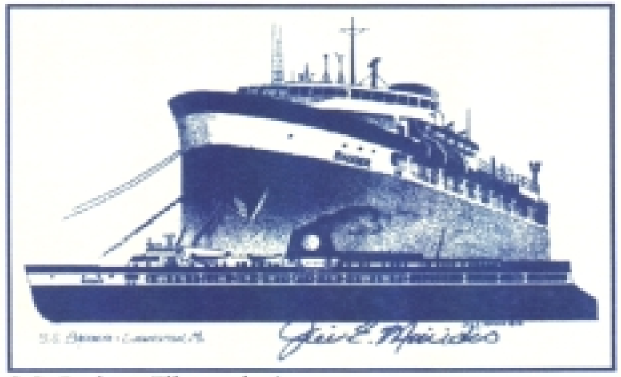
IX. Historical Significance

The *S.S.Badger* and the *S.S.Spartan* were the first marine vessel applications of the Steeple Compound Unaflow design introduced by the Skinner Engine Company in 1950. With the exception of a short period from November 1990 to May 1992 when the ferry changed ownership, the *Badger* has been in continuous service, and this power plant has operated reliably. More than 40 years of service with only routine maintenance is truly noteworthy. This same power plant was also installed on other steam ferries in the United States, however the *Badger* is the only vessel still in operation (The *Spartan* is owned by the Lake Michigan Car Ferry company; however, it is not in running condition.) At the time, the *Badger* and the *Spartan* were the largest car ferries on the Great Lakes. Since the *Badger* and the *Spartan* were so successful, plans were made for an even larger ferry; however, that ferry was never built. Improved rail switching through Chicago made rail freight around the lake more economical and brought the age of large railroad car ferries to a close. Car ferries were used for automobile and passenger traffic, and the *Badger* remains as the only car ferry still in service across Lake Michigan.

To almost 21st century engineers, the power plant on the *S.S.Badger* is a fine example of a well designed mechanical system using an energy source not normally used for this application today. In an age of electronic controls, this is a system with used for this application today. In an age of electronic controls, this is a system with almost purely mechanical controls with operator interaction.

X. Renovation and Conclusion

The renovation of the *Badger* started in 1991 with the purchase of the ship and the *Spartan* by Charles Conrad, a Holland, MI, businessman & entrepreneur. Over a half million dollars in renovations helped prepare the *Badger* for renewed service. The renovations included addition of a lounge, restaurant, retail shop, museum, and updated staterooms. Other than updating the boiler controls and general maintenance, all of the renovations have been in the aesthetics and amenities of the ship; no major mechanical overhaul was required. Although obsolete by 1990's standards, the engineering design of the system and technical skill of the builders has allowed this ship to operate successfully for 40 years with less than two years out of service to date.



S.S. Badger (Illustration)

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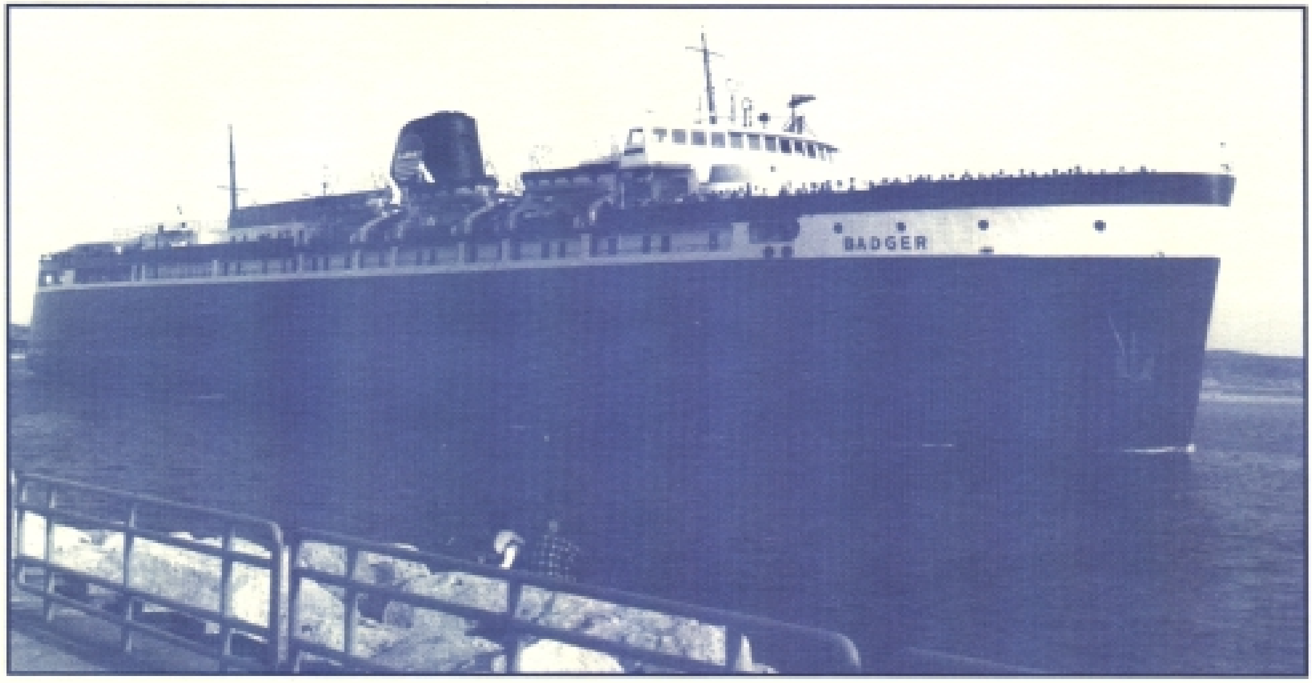

S.S. Badger leaving Ludington port

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