

# Battery Charging Technologies for Advanced Submarine Requirements



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**Requirements for submarines have continuously changed over the years. This article describes how MTU's future submarine engine fulfills these modern submarines' specifications, while also improving the characteristics of the proven Series 396 submarine engines. The availability of the first generating sets is planned for 2016; however, project specific time schedule alignments are possible.**

Starting in 2009, MTU began combining the properties of its existing successful submarine solutions for all customers' submarine designs with new market requests from submarine building shipyards. The resulting product specification was then augmented with the modern submarine requirements (partly described on the following pages). In 2011, the detailed concept study for these functional and performance requirements showed the feasibility of such an improved product. The major challenge facing

the project team was to maintain the benchmark setting characteristics of the Series 396 SE and simultaneously incorporate abilities to meet the latest operational requirements.

Following the successful development of the Series 396 submarine engine, the vast experience gained with the Series 4000 provides a reliable and commercially viable basis for the development of the next generation of submarine engines.



The advanced submarine engine will therefore utilize a large number of proven components from Series 4000 (see Figure 1). As for all predecessor submarine engine designs, submarine specific components are developed to satisfy the demanding operating conditions on board submarines.

**Advanced submarine requirements**

Since the introduction of the Series 396 in the early 1980s into the submarine application, the political map of the world has transformed significantly. This political transition has also altered the tasks of navies worldwide. With new assignments, the requirements for naval platforms, including submarines, have changed and are likely to continue to do so in the near future. The following aspects represent a selection of major changes in the requirements for the diesel powered battery charging units.

Conventional submarines have grown in size over the last decades to meet increased transit distance requirements to the operational areas and to accommodate various Air Independent Propulsion technologies into the hull. Despite hydrodynamic improvements of the hull shapes, the larger displacements have led to higher power demands. This trend for more power will be even further accelerated by new Li-Ion battery technologies. Li-Ion batteries are going to increase underwater endurance and performance of submarines significantly. However, the diesel engine driven charging unit technology needs to adapt to the new requirements: firstly, more electrical power and secondly,

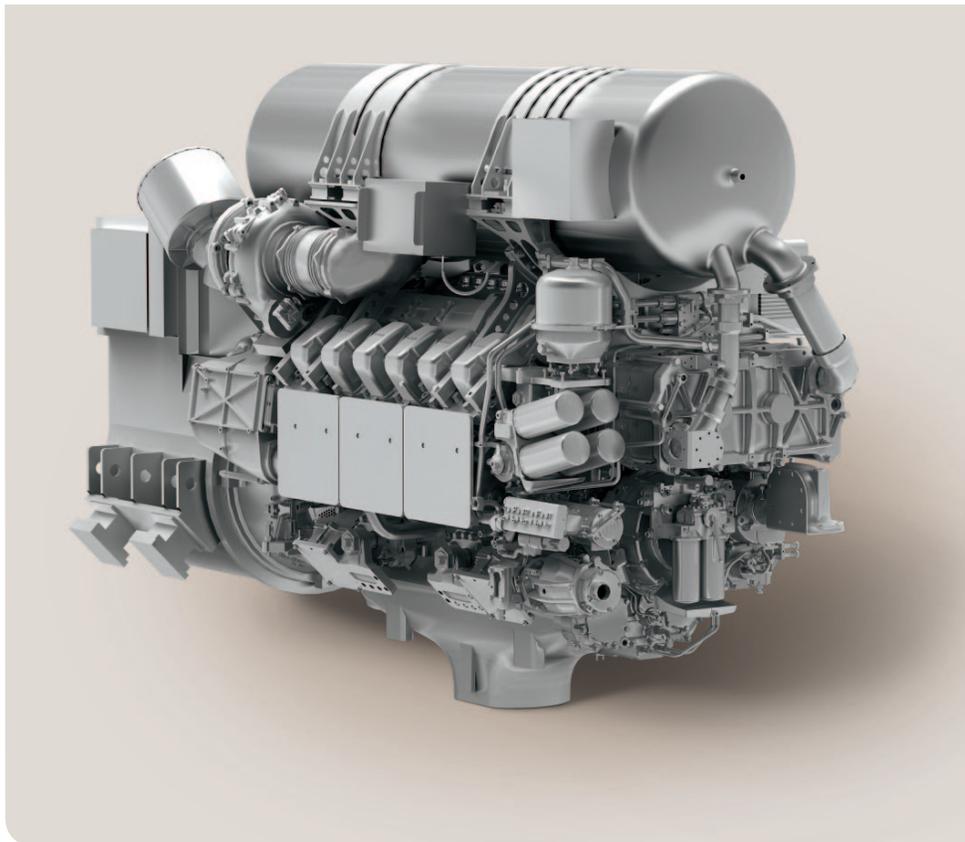
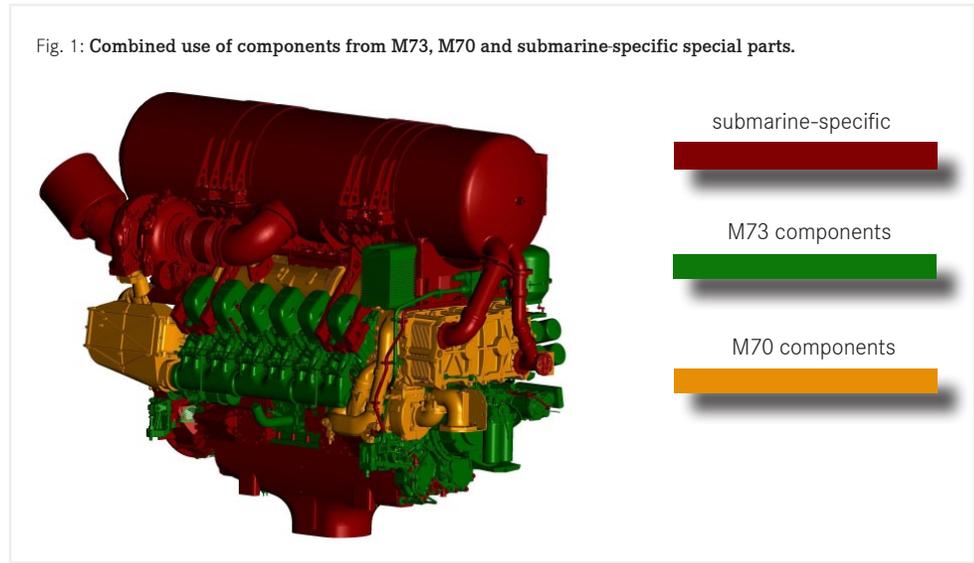
provide rated power almost the entire operational time to fully utilize the Li-Ion advantages.

The task to cover increased transit distances from home port to the theatre of operation is usually covered at relatively high speeds with no specific acoustic signature requirements. Acoustic signature optimization of the combustion process; however, does have a detrimental effect on the specific fuel consumption. To avoid increasing the size of a submarine or limiting its range and endurance it is essential to improve specific fuel consumption in general. When the tactical situation allows, acoustic sig-

nature management in order to reduce the fuel consumption even further, will offer additional operational flexibility.

Emissions legislation gains more relevance even for special applications such as submarines. Public and political pressure to spend taxpayers' money only when complying with emissions regulations is evident in both industrialized and emerging countries. As emissions optimization effects the fuel consumption and emissions legislation requirements vary depending on the platforms geographic position, again more flexibility in the diesel engines' combustion settings is desirable.

Fig. 1: Combined use of components from M73, M70 and submarine-specific special parts.



**12V 4000 Submarine Charging Unit**

MTU's 12V 4000 based battery charging unit is designed to improve the well-known submarine engine characteristics by addressing the advanced submarine requirements

As another aspect, the industry's demand for highly skilled personnel has made it increasingly difficult for navies to recruit and retain sufficiently trained numbers to man their fleets. These continuing crewing challenges will demand a higher degree of automation as well as a reduced degree of equipment maintenance to operate the platforms safely. It is therefore necessary to reduce the number of interfaces to the ship's systems as well as to the human operators.

Limited budgets lead to longer operation of platforms and therefore increased periods between overhauls. To ensure longer operational availability, all system components need to be able to be operated for such increased periods without sacrificing their availability rates. Components already used under maximum maintenance periods therefore need to be modified to meet the new optimum boat maintenance schedules.

Another challenge to meet the tight budget situation is to decrease the overall life cycle costs. Reducing the fuel consumption is one positive improvement which will in addition increase the range of the submarine and is therefore pursued with high priority. The other important LCC factor is maintenance costs including labour and spare parts. If the maintenance periods are increased without increasing the maintenance tasks themselves, this will automatically lead to a reduction of man-hours and spare parts. The costs and availability periods of spare parts themselves can best be influenced by products which are derived from modern COTS commodities.

### Experience gained with Series 4000

MTU's Series 4000 has been successfully established in various applications, including navies, commercial vessels, yachts, locomotives, mining trucks and generator sets since 1996. It is the first off-highway engine with a common-rail fuel injection system. As of today, more than 21,300 Series 4000 engines have been delivered. More than 3,100 of those are used in the marine application. The delivered engines have accumulated more than 35 million operating hours.

### Characteristics of the new submarine charging solution

Due to the great numbers of 16V 396 SE engines in the existing submarine designs, one of the design objectives was to meet dimensions, weights and volume flows of such generating sets as closely as possible. This will allow an installation in existing submarine designs with a minimum of changes to the actual submarine blueprints. A submarine charging unit with a 12V 4000 submarine engine does have smaller dimensions compared to a 16V 396 SE design. However, the mechanical power is noticeably increased to 1,300 kilowatts (kW) at 1,800 rpm. Volume flows of intake air and exhaust gas are slightly higher but almost match those of the 396.

Another major design objective was the reduction of the specific fuel consumption in combination with greater operating flexibilities for different scenarios. A common rail system in connection with combustion processes and modern engine electronics is able to satisfy both requirements. One completely new feature of the Series 4000 submarine engine is therefore the ability to operate in different modes. The standard operation mode is the acoustically optimized mode. In this operation mode, the engine has the lowest air- and structure-borne noise emissions with a specific fuel consumption improvement of at least 5 g/kWh. For long operational periods in transit to the theatre of operations, the engine can be switched to a fuel consumption optimized mode with slightly increased acoustic signatures. This will allow reduced specific fuel consumption by at least 10 g/kWh. Finally, it is possible to select an emissions optimized mode for surface operation. The emissions optimized mode operates under IMO II-compliant conditions without increasing the specific fuel consumption.

With the Series 4000, MTU is integrating the charging unit even further. The charging unit has only one interface to the ship's automation as the generator and exhaust system can be monitored and controlled from the local operating

panel. All power generating system relevant information will be available to the operator in one location and only one person on duty is needed for local operation. The operation of the charging unit can be independent from the submarines' automation system when it is not available. Due to the continuous charging of an uninterruptable power supply directly via generator (including a power safe function during standby), the generating set can be operated under black ship conditions.

The integration of the generator leads to another improvement with regard to the starting process: The engine is now quietly started via the generator. The starting process includes the normal turning and draining process to protect the engine from damage due to hydraulic shock. For emergency purposes an air start motor operating the flywheel is part of the design. However, starting with the air start motor does now also include the turning and drain process to increase the safety even further.

As for all submarine engines, high shock and acoustic requirements demand a special mounting of the generating set. The new engine foot for Series 4000 includes an integrated shock limiter. Its compact and easy to install design (see Figure 2) results in very low effects of the foot's dynamic behavior on the structure-borne noise signature of the engine. In addition, the engine foot also features a very high mechanical impedance at the connection point to the rubber mounts. Therefore the rubber mount's optimum acoustic performance can be taken full advantage of.

One of the most significant improvements, however, relates to the logistics challenges described previously: Maintenance and LCC. Following the operational cycles of a modern submarine with long periods of transit as well as a more demanding Li-Ion-battery based load profile, the complete overhaul of the engine can be increased to more than 20 years. As a comparison, the Series 396 SE engine when operated according to the less demanding lead-battery based load profile does require the first complete overhaul after 12 years. Along with the reduced number of maintenance steps of this modern engine in general, this design improvement leads to significantly shortened maintenance hours and cost.

### History of the submarine application at MTU

1959 marked the birth year of MTU's first engine for the submarine application. The 12V 493 was a naturally aspirated engine with 441 kW at 1,500 rpm. With more than 3,600 units delivered, Series 493 was derived from the well proven Mercedes Benz engine MB820 serving in a broad range of applications such as marine (ca.

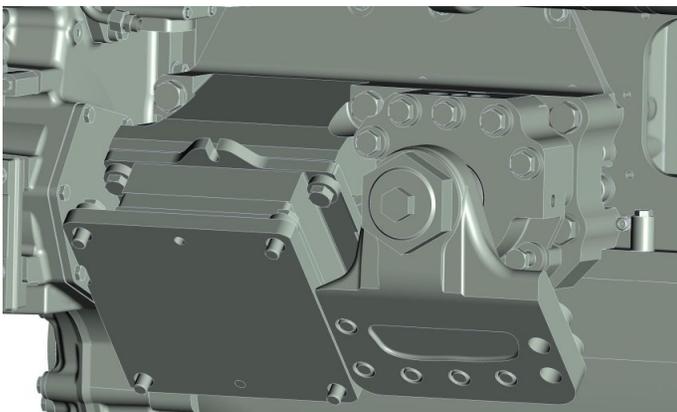
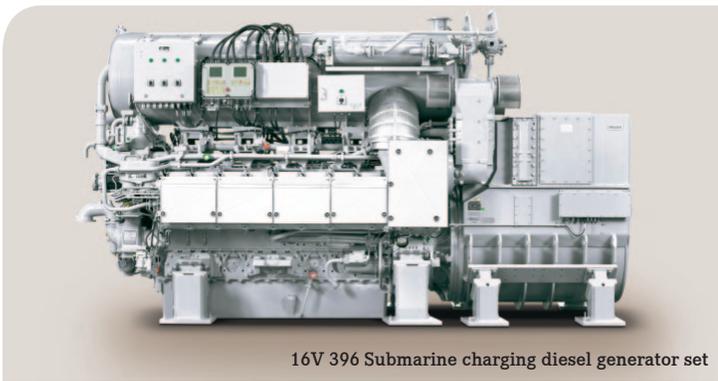


Fig. 2: Integrated engine carrier and shock limiter



16V 396 Submarine charging diesel generator set

Almost 250 delivered units of 8, 12 and 16V 396 submarine engines have accumulated reported unit service times of over 310,000 hours.

1,970 units; see Figure “Naval surface version of a Series 493 engine”), rail (ca. 1,030 units) and power generation (ca. 410 units). Within the marine sector, more than 340 units are used in submarine applications, having accumulated reported service times of more than 1,510,000 hours.

In 1980, power requirements for a larger submarine design led to the development of a variant of the supercharged Series 652. With more than 2,300 units delivered, Series 652 was used in applications such as marine (ca. 400 units), rail (ca. 1,640 units) and power generation (ca. 260 units). No more than 24 units of the submarine version 16V 652 MB81 with 1,200 kW at 1,400 rpm were delivered, as the size of submarines it was designed for did not meet the

tactical needs for smaller coastal submarines of many navies at that time.

Due to increased on-board electronics as well as growing displacements, the power requirements of coastal submarine designs could no longer be satisfied with Series 493. Based on the vast experience gained with more than 15,000 Series 396 engines, which are serving a broad range of applications, the turbocharged and intercooled 396 submarine model has been specially developed for backpressure operation. As early as 1982, a 12V 396 engine was operated under simulated snorkel conditions during an 18 month test phase. Performance verification has been produced with a 12V 396 submarine engine on the occasion of a 1,000 h type test at the Bundeswehr Technical Center for Ships and Naval Weapons, Maritime Technology and Research (WTD 71) in Eckernförde. This type test has been completed successfully. Analysis proved the impeccable state of all component parts, with no measurable wear. In 1987 the first 16V 396 SB83 engines delivered 970 kW at 1,800rpm.

Design improvements of Series 396 continued and in 1990 Series 396 SE84 was established with 8, 12 and 16V configurations delivering up to 1040 kW at 1,800 rpm. As the size and power demand of the submarine designs continued to grow over the years, MTU introduced modernized and updated version of its Series 396 SE84 in 2002. The "L" in all cylinder variants of Series 396 SE84 L indicates the higher power rating up to 1,200 kW at 1,800 rpm of the current submarine engine offered by MTU.

The success and economic benefits of this development are proven by the number of incoming orders for 8, 12 and 16-cylinder models. Meanwhile almost 250 delivered units of 8, 12 and 16V 396 submarine engines have accumulated reported unit service times of over 310,000 hours. Before the turn of the century, the huge success of Series 396 SE led to the use of MTU's submarine engine also in nuclear submarines. With MTU driven emergency generating sets, nuclear submarines can utilize the less visible snorkeling mode even under emergency conditions of their main power plant.

The high market acceptance of MTU's submarine solutions in combination with the positive feedback from operators worldwide continues to motivate the company to improve its products further. It is the defined goal of MTU to stay the reliable partner of all navies as well as for their special applications such as submarines.

### Summary

The operational scenario has changed significantly over the last thirty years. Together with technology advancements, this has changed advanced submarine requirements. These surpass the continuously improved and well established submarine engine designs. MTU's 12V 4000 based battery charging unit is designed to improve the well-known submarine engine characteristics by addressing the advanced submarine requirements.



Fig. 3: Naval surface version of a Series 493 engine

**MTU Friedrichshafen GmbH**  
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September 2011

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