NOx emissions are reduced

NOx emissions from the cracking heaters operating on TEG are lower than before the integration system was installed, even though the TEG combustion air’s NOx content is higher. Typical NOx concentrations in the heater effluent are 70 ppm with TEG and 95 ppm without TEG. The figures are based on dry gas and 0% oxygen content.

The saving in energy is considerable

The overall energy improvement achieved by integrating the cracking heaters with the gas turbine is shown in Table 5. With the integrated system, fuel fired in the cracking heaters decreases significantly while steam production increases. Overall, 30.41 million kcal/h of energy are saved. This translates into approximately 800 tons/ Kg ethylene, which agrees favorably with the estimates given in Tables 1 and 3.

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**Table 5: Energy improvement achieved with gas turbine integration at Osaka Petrochemical, Japan**

<table>
<thead>
<tr>
<th></th>
<th>Without gas turbine</th>
<th>With gas turbine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethylene production (kta)</td>
<td>300,000</td>
<td>300,000</td>
</tr>
<tr>
<td>Fuel fired (Gcal/h)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cracking heater</td>
<td>Base</td>
<td>20.76</td>
</tr>
<tr>
<td>Gas turbine</td>
<td>0</td>
<td>63.18</td>
</tr>
<tr>
<td>Total</td>
<td>Base</td>
<td>42.42</td>
</tr>
<tr>
<td>Steam production increased (th)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>From cracking heater</td>
<td>Base</td>
<td>21.41</td>
</tr>
<tr>
<td>For fuel vaporizer of gas turbine</td>
<td>0</td>
<td>2.1</td>
</tr>
<tr>
<td>Total</td>
<td>Base</td>
<td>19.96</td>
</tr>
<tr>
<td>Electric power generation (kW)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas turbine</td>
<td>0</td>
<td>23.827</td>
</tr>
<tr>
<td>Increased power associated with gas turbine</td>
<td>0</td>
<td>-405</td>
</tr>
<tr>
<td>Total</td>
<td>0</td>
<td>23.422</td>
</tr>
<tr>
<td>Energy improvement (Gcal/h)</td>
<td>Base</td>
<td>30.41</td>
</tr>
</tbody>
</table>

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**A new locomotive speeds up transalpine rail traffic**

Traction equipment of the class 1822 dual-system locomotive

Austrian Federal Railways’ class 1822 dual-system locomotive, referred to locally as the ‘Brennerlücke’, or ‘Brenner locomotive’, is the product of an Austrian industrial group led by ABB. The new locomotive solves problems that are caused by the different catenary voltages on the north and south sides of the Brenner Pass; Germany and Austria use AC at 15 kV and 16.7 Hz, Italy DC at 3 kV. The railway authorities of Germany, Austria and Italy were also involved in the design of the vehicle, giving the locomotive a number of innovative technical features that break with the railway traditions of the three nations.

Austria, situated in the heart of Europe, has a long history of transit and trade traffic, and several of Europe’s main railway routes run through the country. Both Germany and Switzerland use the same catenary power system as Austria, but the other countries bordering Austria use a variety of systems. Uninterrupted rail transit through this part of Europe is essential for economic transportation and to achieve capacity goals. Only locomotives that can be operated with different catenary voltages allow this.

**Main specifications of the locomotive**

The class 1822 locomotive is designed for trans-continental services over the Brenner Pass, and in particular for piggyback rail traffic between Germany and Italy. Five units have been manufactured as part of a first pre-production series.

Table 1 lists the locomotive’s main specifications. The traction and the traction power of 4400 kW are the result of data specified by Austrian Federal Railways (ÖBB). They will allow trains weighing 1100 t to be hauled up the northern side of the Brenner Pass, which has rating gradients of up to 2.8 percent, at 70 km/h in dual traction. This corresponds to the drawbar power limit. On the downhill sections the train has to be able to run at speeds of up to 120 km/h with the same load. The 4400 kW at the motor shaft takes account of the locomotive’s own weight and the required acceleration reserve. This power is provided by both the AC and the DC catenary system.

The overview in Fig. 4 shows the main traction power circuits.
The class 1822 dual-system locomotive includes many innovative features, such as a device for identifying the traction power system and a system transfer switch which ensures protection against erroneous action by the driver during raising of the pantograph(s).

State Railways (FS), it ensures that the total impedance is 2.5 ohms at 50 Hz. The second reactor, also with two windings, is connected to capacitors to form the two series resonant circuits for 33 Hz.

The transformer unit is fully oil-cooled. The heat is dissipated by two ovo-circuits, one for each bogie. This arrangement allows part-load operation of the transformer if one bogie fails, enabling the other bogie to continue running. Since the temperature of the oil circuit is monitored, the fans only have to be run when necessary.

Starting at the transformer secondary windings, the power circuits of the converter system are arranged in a two-channel configuration, i.e., each bogie has its own separate channel. The same applies to the main control system and the auxiliaries, underscoring the principle of redundancy that is employed throughout the circuits.

A new three-point circuit for the converter

The converter system consists of the input converters, DC link and drive inverters. The class 1822 locomotive is the first dual-system vehicle to employ ABB’s newly developed three-point converter circuit, which allows access to the direct voltage neutral in the DC link. Because of this special configuration the GTO thyristors are connected in series, and the motor windings can be switched into the circuit in two steps. The advantage of this is that reactors are not needed in the incoming circuit. Neither does the voltage rise as steeply, which reduces the stresses that the insulation has to withstand.

By using GTO thyristors with an off-state voltage of 4.5 kV and a turn-off current of 3 kA in combination with the new circuit, it has been possible to achieve a nominal DC link voltage of 3.5 kV, with a maximum value of 4.2 kV. As a result the 3-kV voltage on the Italian catenary can be fed directly, via just the reactor in the incoming circuit, to the DC link. There is no need for an input chopper to reduce the mains voltage. The converter system was designed by ABB and built by Siemens. Both the input converters and the

Traction power systems used by Europe’s railways

- Brown 16 kV, 16½ Hz
- Orange 25 kV, 50 Hz
- Yellow 1.5 kV (DC)
- Green 3 kV (DC)
- Violet 600–1200 V (DC)
- White Steam or diesel locomotives

ÖBB’s class 1822 dual-system locomotive, designed to run on the Brenner Pass route

Tractive effort versus speed diagram for the class 1822 locomotive

- Z Tractive effort
- \( v \) Speed
- P Power

\[ P = 4400 \text{ kW} \]
drive inverters are modular constructions. All the semiconductor devices are vapour-cooled.

The input converter is a four-quadrant controller which feeds the nominal 3900 VDC to the intermediate DC link. This controller allows energy to be taken from the catenary with a displacement factor and a power factor which are virtually unity.

The DC link has a series resonant circuit tuned to 33½ Hz, as filter, and a back-up capacitor. By storing energy, the latter ensures that the inverter supplies a constant AC power to the traction motors despite the catenary delivering pulsating, single-phase power. The speed of the traction motors is controlled by varying the voltage and frequency.

On the sections of route served by the AC catenary, energy is recovered during braking and can be fed back into the catenary via the four-quadrant controller. The maximum recoverable energy is 4400 kW.

Protection for the converter is based on the principle of 'preventive turn-off'. The state of the GTO thyristors is detected by the thyristor control units and signalled back to the drive controllers. These prevent critical turn-on malfunctions. A fault or defect causes a turn-off signal to be sent to all the GTO thyristors. If, as a result, the DC link voltage increases during braking, a resistor is connected into the circuit to dissipate the additional energy before the acceptable limit for the off-state voltage is exceeded. The protection has five hierarchical levels, each with different consequences for the system. The lowest level is permanently active during normal service, and operation is not disrupted when it responds. The protection at the highest level is only tripped when there is serious danger, in which case it disconnects the converter one bogie at a time.

The converters feature advanced control

A newly developed system of direct self-regulation is used to control the converters in the class 1822 locomotives. The magnetic flux and torque values are calculated from the voltage, current and motor speed, and then compared with the setpoint values. The torque controller transmits only two commands, signalling agreement with 'yes' or deviation with 'no'. Control takes place within a narrow tolerance band and with the maximum possible pulse frequency.

The new method was made possible by use of advanced microprocessor systems from the latest range of Micas equipment.

Cage-induction traction motors are used in the new locomotive

The successor to the single-phase commutator motor and the pulsating current motor in the 'thyristor' locomotive, the three-phase cage induction motor in the class 1822 unit is the 'ideal' traction motor. Rugged, lightweight and requiring only minimal maintenance, its use is made possible by modern inverter technology. Open-type cage induction motors with six poles are used in the 'Brenner' locomotives. The winding insulation in the forced-ventilated machines conforms to insulation class 200 - a new class allowing a temperature rise in the windings of 200 K. Table 2 gives the main motor specifications; all the nominal data are continuous ratings.

**Table 2: Technical data of the traction motors**

| Nominal power | 1155 kW |
| Phasen-st.-phase voltage | 2190 V |
| Nominal current | 635 A |
| Maximum current | 644 A |
| Nominal speed, frequency | 1300 rpm/min, 55 Hz |
| Maximum speed, frequency | 2300 rpm/min, 145 Hz |

The motor used in the class 1822 locomotive weighs 2100 kg. Fig. 7 compares the respective weights and volumes of the induction and pulsating current motor for a comparable power rating.
The MICAS S2 distributed control system employs modules situated at the load centers and communicating with each other over a high-speed vehicle bus. This saves numerous cable connections, and there is no need for a busmaster.

The stations located at points along the bus form the smallest functional units of the traction control system. The hardware is connected to the local process peripheral over the shortest possible length of conventional cable. Both analog and digital signals can be exchanged.

Power is supplied to the auxiliaries on a per-bogie basis. The auxiliaries are supplied with power on a per-bogie basis by static converters connected to the DC link. There are two outputs for each converter – a variable frequency output for the parallel-connected fans which cool the traction motors, main converters and oil-coolers, and a constant frequency output for all the other loads, including the battery charger. Special socket outlets are provided for supplying the auxiliaries with external power during testing.

The distributed control electronics works with high transmission speeds. The locomotives are controlled and monitored by MICAS S2, a digital, distributed traction control system with modules located at the load centers and connected over the MICAS vehicle bus. This allows a considerable reduction in the amount of cabling needed. Fig. 8 shows an overview of the control system.

### Comparison of an Induction Motor and Commutator Motor for a Similar Power Rating

<table>
<thead>
<tr>
<th>Type</th>
<th>Power Rating</th>
<th>Speed</th>
<th>Torque</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>1250 kW, 1130 rpm, 18.1 Nm</td>
<td>1000 mm, 3750 kg</td>
<td></td>
</tr>
<tr>
<td>b</td>
<td>1165 kW, 1300 rpm, 20 Nm</td>
<td>880 mm, 2100 kg</td>
<td></td>
</tr>
</tbody>
</table>

### MICAS S2 Control Electronics – Diagram Showing the Signal Paths

1. Driver’s cab I
2. Driver’s cab II
3. Motor compartment
4. Main power cubicles
5. Motor compartment cubicles
6. Electronics cubicle
7. Data bus stations, cab I
8. Data bus stations, cab II
9. Data bus stations, control current unit
10. Vehicle controllers
11. External electronics
12. Data bus stations, auxiliaries
13. Data bus stations, control current unit
14. Onboard system converters
15. Converter electronic I
16. Converter electronic II
17. Speed measurement
18. Displays
19. Braking computer
The driver’s cab was developed jointly by the Austrian, German and Italian railways, and has technical features that break with the railway traditions of the three nations.

Regular service is due to start by the end of 1992

After completing tests in Austria and Italy, the preproduction series of class 1822 locomotives will go into operation on the Brenner route by the end of 1992. It is expected that later a large series – a total of 80 of these dual-system locomotives are planned – will substantially increase capacity on the Munich-Zürich route, and so relieve the tense transit situation on this line. The locomotive can be easily modified to allow it to also be used with systems operating at 25 kV and 50 Hz. This conversion would make it suitable for use throughout Europe.

Authors’ address:
Peter John
Hansjörg Lachtmad
ABB Verkehrstechnik Gesellschaft m.b.H.
A-2251 Vienna, Austria
Fax: +43 2226/34417

The user-friendly driver’s console was developed jointly by the railway authorities of Austria, Germany and Italy.

The variable-speed, converter-fed cage induction motor operates with low losses over the full speed range. It is used mainly in compressor drive applications. If the drive can be made gearless, its cost can be reduced and it will also be smaller. High availability is ensured for this kind of drive by modern power electronics.

Power electronics moves variable-speed drives with a cage induction motor to higher power levels

Inverter-fed induction motors for the megawatt range

With the help of modern converter technology, drives with induction motors designed for the megawatt range and speeds of 3000 rev/min and higher can be built today as variable-speed units. They are mainly used as compressor drives in the chemical and petrochemical industries. ABB confirms the good design and operating behaviour of ordered motors in its own factory prior to delivery.

Designers of drives fed from a voltage-source inverter have to pay attention to a number of points:

- Bending (lateral) critical speeds are not allowed to occur at any point in the speed range for which the unit is designed. Despite high speeds, the vibration severity recommended for electrical machines should not be exceeded.
- The centrifugal forces caused by the high speeds must not lead to excessive mechanical loading in any part of the machine.
- The high fundamental frequency of the current and the converter voltage harmonics cause additional losses, pulsating torques and ‘magnetic noise.’ Temperature rise, shaft train loads and environmental impact all have to be kept within acceptable limits.
- The aerodynamic, or ‘windage’, noise increases with speed, but should not exceed the usual levels for electrical machines when possible. Neither should the mechanical losses, which also increase as the speed rises, significantly reduce motor efficiency.

Proper design is a guarantee for reliability

Bending critical speeds

For the power and speed ranges indicated, it can happen that a natural bending frequency of a rotor designed for a mains-operated machine will lie within the area of the operating speed or too close to it. Operation close to a bending critical speed is a cause of disturbance and has to be avoided; some standards (eg, API 544 of the American Petroleum Industry) even prohibit it.

In the first place, it is the rotor that has to be dimensioned so that its flexural strength will guarantee that no bending critical speed can occur in the operating range. Two different cases have to be considered:

- Case A: The operating speed range is so large – in the extreme case from a fraction of the maximum speed to the maximum – that the first bending critical speed has to lie above the operating speed range. The motor has to be designed for speeds below critical.
- Case B: The operating speed range lies between the first and the second bending critical speed (the speed range in which the first critical speed occurs is simply passed through during the run-up). The motor has to be designed to run at speeds above critical.

In case A, the first bending critical speed has to lie far enough above the highest operating speed. In case B, the first bending critical speed and the lower speed, as well as the second bending critical speed and the upper operating speed, must be sufficiently far apart.

Several international standards specify a difference of up to 25 percent between the operating range and the bending critical speeds for mains-operated motors. Differences of this order are not always possible with inverter-fed motors with high power and speed ratings; neither are they necessary when the rotor has been properly manufactured and balanced.

Fig. 2 compares cases A and B in terms of rotor shape and behaviour at bending critical speeds.

The shaft of the rotor for speeds above critical (Fig. 2a) is narrower, being similar to that of a mains-operated machine. The shaft for speeds below critical (Fig. 2a) is thicker compared with the rotor’s outside diameter, and the distance between the journals is comparatively small.

It is seen from the speed versus total bearing flexibility curve in Fig. 2 what an important role the compliance of the