Syntegra® –
The intelligent Integration of Traction, Bogie and Braking Technology

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Summary

With Syntegra technology, Siemens opens new horizons for metro, underground and commuter trains. Syntegra integrates traction, bogie and brake systems to a compact powered bogie concept, which will enable higher efficiency, lower dead weight and reduced emissions than any other conventional systems. In addition this new generation of powered bogies decrease life cycle cost. The integration and moreover the technological advances within the three systems bring about many synergies and advantages compared with today's state of the art. In the Siemens test facility in Wegberg-Wildenrath and in Munich's metro network the prototype testing is on its very promising way. This paper presents this rather radical or disruptive innovation.

Development to a new direction

In the majority of powered railway vehicles the drive systems are based on three-phase induction motors. Bogie and brake equipment are basically autonomous elements. Development up to now was achieved by optimising components and subsystems.

Siemens went a different way compared with other competitors. Instead of improving subsystems, Siemens offers a unique innovation for the mechatronic system of powered bogies. The mechanically highly complicated traction drive is replaced by a simply structured permanent magnet three-phase synchronous direct drive completely integrated into a new kind of bogie. The traction motor thus becomes an integral component of the bogie. The whole system is a compact one that enables mass reduction and more efficiency of traction power. The inherent electrodynamic brake, which is also a part of the new system, can replace the conventional fully fledged mechanical brake as a fail-safe electrical brake. This leads to a reduction of emissions of noise and particulate matter especially in tunnels as well as to less expenditure for maintenance.

Direct Drive

State of the art in present-day metro trains with under floor traction equipment is propulsion by a drive system comprising a traction converter to feed two to four induction traction motors. In that case the torque has to be converted by a gearbox mounted on the wheel set, which causes a lot of disadvantages.

The development of the Syntegra drive system followed a different approach. A reasonable solution for a direct drive could only be based on permanently excited synchronous motors without any need for gearboxes. The rather classically structured permanent magnet synchronous motor with a radial-flux arrangement and three-phase windings is ideal for the tubular-shaped space available around a wheel set. [1,2,3]

The basic concept of the drive system has been developed for a high-speed train application and is now adapted for a totally integrated drive for a metro or commuter train. Fig. 1 shows the
schematic longitudinal cross section of the gearless drive arrangement. The stator housing is made out of an cast iron piece with rectangular cross-section. The wheel set carries a rotor hollow shaft which is shrinked stiffly on the two ends. The rotor hollow shaft itself carries the permanent magnets made out of NdFeB.

Fig. 1. Longitudinal cross section of the Syntegra direct drive
1 Stator winding, 2 Permanent magnets, 3 Rotor, 4 Main bearing, 5 Primary suspension spring

One of the fundamental innovations in the transition to an integrated direct drive is related to the combination of the wheel set bearings and the motor bearings to form a single main inside bearing. From the point of view of operating the train there are many advantages in having axles driven individually rather than as groups. One of these is that there is no longer any constraint on behalf of diameters differences of the wheelsets when reprofiling. Thanks to active conditioning implemented in a modern slip-slide traction control, it is possible to increase the adhesion between the wheel and the rail when the initial friction coefficient is low. Vibrations are much lower when the slip-slide control acts on individual wheel sets.

The traction drives are operated sensorless using the new Sitrac traction control. Syntegra’s particular control method interprets only the measured phase currents and the voltage of the intermediate circuit. Thanks to this field orientated control as a function of the position of the rotor, the use of the electrodynamic service brake to bring a train to a complete standstill is fundamentally much simpler than performing the same operation with induction drives. [4]

Before having been integrated into the prototype train the new Syntegra direct drives have passed intense testing. Fig. 2 shows one of the traction motors on the test-bench.

Fig. 2. Syntegra direct drive on the test-bench
Within these tests both electric and mechanic characteristics of the drives have been validated. First the simple free running test indicates proper design of the magnetic circuit. After commissioning the whole control system the so called system test program is applied. During this system test the drives act as in regular service. Therefore realistic load cycles have been applied to the drive. [5]

**Bogie**

The overall length of the prototype bogie is 2400 mm. The highest point of the bogie is the top edge of the wheels. The prototype Syntegra bogie has a wheelbase of 1600 mm. Given the reduction in the mass of the bogie and especially in the moments of inertia around the vertical axis, its stability behaviour corresponds to that of conventional forms of bogie with longer wheel-bases. For an equivalent conicity of tan \( \gamma_e = 0.6 \) and a 5 % remaining damping, the prototype as built has a maximum speed constraint of about 100 km/h. There will be no difficulty at all in designing for higher speeds.

Figure 3 displays the main item of the Syntegra bogie – it’s fully flexible main frame. The prototype has wheels with a diameter of 690 mm/630 mm for an axle load of 14 tonnes.

![Fig. 3. Syntegra bogie frame (without traction motors)](image)

The Syntegra frame is comprised of two longitudinal beams and one cross beam held together by joints, thus avoiding the conflict between torsional strength and roll stiffness. Trains with Syntegra systems can be designed for very high payloads, since the stiff primary suspension necessary for that purpose does not increase the derailment risk for the unloaded vehicle.

Due to the coaxial traction motor construction the space requirement of the traction drive is minimized. All tractive effort and traction torque is transferred directly from the bogie to the vehicle body using a pair of rods. Inboard bearings are used to integrate the bearings of the axle-mounted gearless motor and the motor bearings. The driving wheel set has only two bearings. As a result the high integration level leads to lower mass of the bogie.
As a further advantage of the system there is a symmetrical load acting on the traction motors, which permits optimum use of the installed traction power. Despite Syntegra’s short wheelbase, the loads acting on the wheel sets remain much more constant than with other transmission systems. Figure 4 gives a comparison of the load shift of a conventional bogie system and Syntegra. Generally speaking a conventional bogie systems act's bogie related, nearly compensating the load shift within the bogie itself. Despite to this Syntegra uses the bogie center distance of the car to compensate the weight shift, and therefore provides a weight shift of less than 75% compared to a conventional system. Regarding the smaller wheelbase the advantage of the new system even rises.

Regarding the impact on the track not only the unsprung mass, but also the moment of mass inertia around the longitudinal axis (x-axis) of the bogie is decisive. With the same unsprung mass as a conventional traction bogie, Syntegra has a reduction of Jxx by approximately 40%. As shown in Figure 5 the impact on the track is reduced.
Brake system

On metro vehicles the current state of the art is to use two brake systems that are independent of one another, mostly electrodynamic and electro-pneumatic friction brakes. These conventional railway vehicles use electro-pneumatic friction brakes in case of emergency braking even if the electro-dynamic regenerative brake is ready for operation. Therefore a lot of components are necessary for air supply and reliability and availability requirements are high.

Syntegra offers the possibility to simply implement a mechanical brake with a significantly reduced actuator force for holding the train at platforms, as a parking brake in the depot and to partially support the emergency brake. For this purpose it uses the small, lightweight, economic and well proven tread brake, which is perfectly adequate for the reduced demands. Permanent magnet synchronous motors have the property of being able to decelerate the vehicle to a standstill when switched in series with a resistor without the need for any additional control component. This effect is used by the patented Inherent Electrodynamic Brake. The IED brake as a second independent brake circuit alongside the electrodynamic brake is comprised of an additional braking contactor and an additional brake resistor.

The concept of fail-safe electrical brakes exploiting the physical properties of synchronous motors is capable of replacing the full-range mechanical brake that is usual today. The IED brake is comprised of far fewer components than conventional mechanical brake systems. Moreover, this arrangement offers genuine redundancy, since the IED brake is actually subdivided into individual systems for each wheel set. The availability of the second brake system is thus generally higher than with today's mechanical brakes. The reaction time between triggering the IED brake and the availability of its maximum braking torque is less than 150 ms, which is much faster than the mean reaction time of compressed-air brake systems, which typically responds after 1.5 seconds. [6,7]

The safe electric brake system consists of the PM machine, a three-phase brake resistor, brake contactor and a power contactor. Figure 6 shows the electric brake circuit of one direct drive.

![Fig. 6. Safe electric brake circuit](image)

The maximum braking torque is defined with the machine parameters and can be shifted along the speed axis by varying the ohmic value of the brake resistor as shown in Figure 7.
A strategic partnership for testing the new Syntegra system was agreed between Stadtwerke München (SWM, the Munich metro operator) and Siemens right at the start of the project-planning phase. SWM, as the subsequent operator, supplied valuable inputs even during the prototype’s conceptual-design phase. Syntegra equipment has now been integrated into a present day metro vehicle of SWM. The actual testing of the new technology is carried out in three stages.

Stage one took place at Siemens’ own test facility in Wegberg-Wildenrath, Germany, where the vehicle was run and tested according to a commissioning plan. A railway test centre with the unique capability of the Wegberg Wildenrath facility (PCW) provides the ideal location for this sort of work. Nearly all the circumstances likely to affect a train in normal operations can be simulated there. Being able to mimic fluctuations in supply voltages, gaps in the third-rail voltage supply, different payload levels and various driving patterns in laboratory conditions constitutes an essential foundation for confirming the soundness of a new technology. The extensive tests necessary for approval were mostly carried out there. The supervision and conduct of the tests has been entrusted jointly to experts from Aachen University (RWTH) and the validation centre (VC) within the Wegberg Wildenrath facility. The PCW centre has been recognized as a test centre by the German Federal Railway Authority (EBA) and is also in charge of coordinating the approval. The main focus of the tests in Wegberg Wildenrath, which were successfully finished in summer 2007, was lying on first operation, examination of all system components and examination of the traction software. Most of the tests for admission to passenger operation have been passed in the Test Center too. Fig. 8 gives an impression of the static envelop test.
The dynamic tests, including driving and braking performance, as well as security aspects have taken place in the test centre too. Fig. 9 shows the train on the track simulating passenger operation.

As follows some of the test results are:

With a measured efficiency at full load of more than 94 %, the Syntegra drive scores exceedingly well for a 150-kW railway drive. Its improvement in efficiency compared with a standard drive is particularly high when running under a partial load – a situation which occurs frequently in railway operations and which is thus particularly important.

The comparison with conventional bogies shows Syntegra’s mass advantage for the same tractive effort and carrying capacity. The weight of the prototype with a projected wheel set load of 14 tonnes is 1000 kg less than the current state of the art. With the measures that now seem certain to be implemented, the target for a unit manufactured in series is to get close to 2000 kg lighter than the current state of the art. Taking just the level of the vehicle systems, there are already numerous advantages to be derived from using the prototype technology. Taking a whole metro train set and assuming a standard style of driving, the reduction in energy consumption is up to 20 %. [5]
The unsuspended mass of the prototype’s powered bogie is equal to that of present-day bogies. The mass of the direct drive supported on the axle is almost entirely offset by overall savings in the mass of the wheel set, the elimination of the gearbox and the brake discs as well as the integrated suspension for both the wheel set and the traction motor. Extensive studies have shown that the prototype system in the speed range of up to 120 km/h no limits need be placed on axle-supported traction motors for reasons relating to the dynamics of vehicle movements or the forces acting on the track. Speeds of up to 160 km/h for (urban) regional-express and local-passenger-train services are feasible. Measured ride comfort corresponds to that of comparable modern conventional bogies. [8]

As an example Figure 10 gives a comparison of a conventional powered bogie and the Syntegra system. Both bogies offer the same installed power, maximum speed and payload.

![Fig. 10. Outer dimensions of a conventional (blue) and the Syntegra system (colored)](image)

**Syntegra – test phase 2 in progress**

At the end of summer 2007 the prototype was transferred to Munich, the testing entered stage two. The prototype with the Syntegra system is running in the Munich metro network under real operating conditions, performing extensive tests on behalf of the stability of components, the running characteristics, the total driving behaviour and the verification of load-collectives. Various scenarios of operation are being carried out. Syntegra has passed the admission of the German railway authority. So all the measurements already in test phase 2 are carried out in a metro network which is in passenger service (figure 11). This explicitly demonstrates that all goals of the new technology are reached and Syntegra as a system is working soundly.
The ongoing operation in daily passenger service is the third stage of the technology testing. The results from the long term testing will be included direct into series production.

**Conclusion**

The Syntegra powered bogie is the basis for a new bogie generation. Modern railway systems put extremely challenging demands on vehicle technology. Depending on the specific environment, all technical systems must be able to make optimum contributions to the overall system performance. In this respect, Syntegra technology is capable of setting a new milestone also from an economic point of view, thanks to its technical and design advantages.

The novel totally integrated gearless drive system Syntegra offers the wide-area benefits, e.g.:

- higher efficiency of the traction motor
- reduced total mass of the total bogie
- no gear energy losses or gear maintenance
- increased payload
- reduced noise
- no coupling adjusting or maintenance
- reduced rotating mass of the driving wheel sets
- wear-free electrical emergency brake

It is assumed that the first series manufactured vehicle incorporating Syntegra technology could enter service in two years time. The next development steps are going to focus on ensuring maturity for series production and further mass reductions by optimising individual components and by switching over to new manufacturing methods or alternative materials.
### References

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