ELECTRIC TRACTION SET FOR A LIGHT CAR

Stefano Uberti, Danilo Cambiaghi, Valerio Villa
Dipartimento di Ingegneria Meccanica
Facoltà di Ingegneria, Università degli Studi di Brescia
Via Branze, 38
25123 Brescia
Italy
uberti@ing.unibs.it

ABSTRACT
This paper deals with the feasibility study of a special electric traction wheel-set for a micro-car for disabled customers. In our university department some solutions on the topic had already been developed in the past. The design has not been carried out in a sequential way, but it has been lead in "concurrent-engineering" style and it has been speeded up thanks to the employment of solid modelling. The 3D design technology has helped in a very efficient way to take into account the impact of any modification on any component to the neighbouring items. The following topics have been considered: design for disabled customers, maximum ease of use and low cost technology.
This job therefore has coped the main problems related to designing a new car. Some innovative solutions have been proposed and an overall design procedure has been experienced.
This paper in particular describes the results of a research activity connected with the study of the general lay-out of such a wheel set. Some different configurations were explored, each showing its strong and weak points. It is to point out that, while the traditional arrangements connected with gasoline or diesel engines were hugely studied, with the electric traction all the wheel sets must be reshaped. In fact too many car designers tend to use the same lay-out used before, wasting much of the potential advantages offered by electric motors.
During this study some radically new designs were explored, for example not using any live axle for transmission or trying to use thrust ball bearing for steering axles.
In the following a gallery of proposed and studied solutions will be exposed, showing the most characteristic points.
We developed the study and design phases starting from some specifications: the group must be composed by electric motor (geared or not), brake, wheel hub, front or rear traction, in case of front traction the group must have steering pivots (attachments for steering rods).
This apparatus has been designed to be used in a light car (which is under development in our faculty). However the proposed design may fit even standard city cars.
Design goals were: 1) Keeping very low steering radius (intended use in city environment) 2) Absence of traditional suspension system (our light car has some innovative design in this) 3) Respect of Ackermann geometry.
Some different design solution have been developed and are exposed in the paper. The most relevant feature is that every wheel has its own motor, so achieving a dramatic reduction in encumbrance.

Keiwords: urban car, electric motor, electric traction, upright.

TECHNICAL SPECIFICATIONS
The theme of the project is to study a traction wheel-set for MarGO vehicle; this vehicle is under development by "Disegno Di Macchine" (machine drafting) research group.
This car represents an innovative urban micro-vehicles sector because it is able to satisfy various customer classes as mailmen, disabled, home deliveries etc…In this market segment micro-cars and/or quadricycles can be found. The following table shows a reference set of technical features.

Engine	2 brushless electric motors (tot. 4kW)
Chassis/bodywork	Aluminium extrusion/ thermoplastic resins - total weight 400 kg
Tyres	135/70 R13
Dimensions	Lenght.=2500mm / width.=1500mm / Height.=1700mm
Wheelbase	2000mm c.a.
Suspensions	In definition phase
Performances	45 km/h (law limitations)
Autonomy	80 km. (with 8 12v pb-gel batteries)

Table 1

It is to be remembered that this wheel-set is lacking of suspension; so it has to be linked to a suspended sub-frame.

SOLUTION N° 1: FRAMELESS BRUSHLESS MOTOR

This solution is characterized by two electric frameless motors on the front wheels, with a steering geometry with 21° sloping arms, so internal and external wheels rotations are not equal (figure 1). Wheel hub and upright are integrated in motor's external frame designed on purpose.

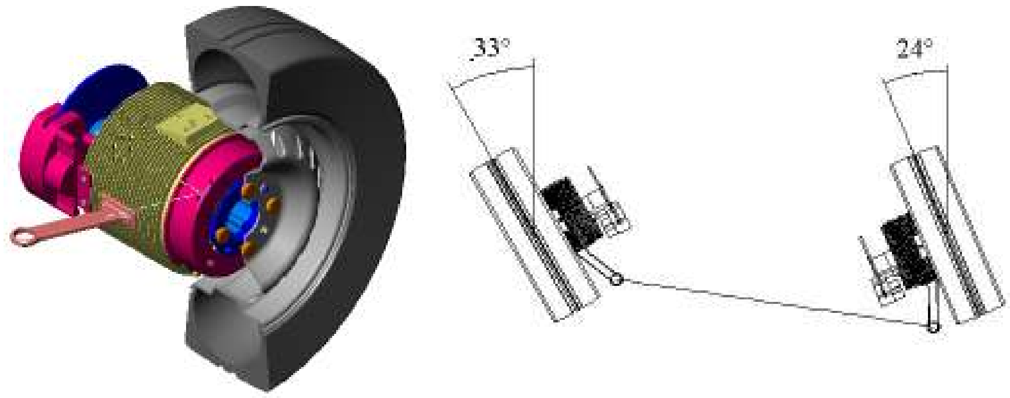


Figure 1

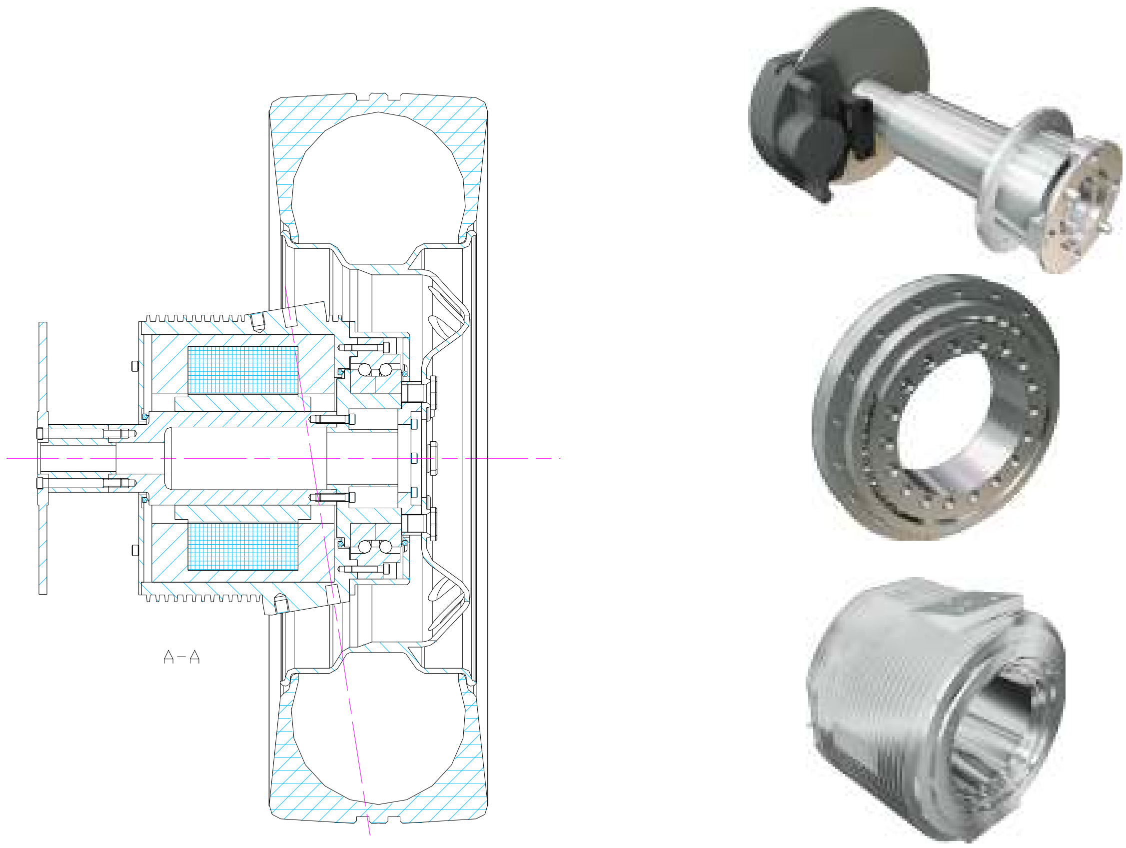


Figure 2

Gearboxes are not required because a rotation speed which perfectly fits the speed specifications is available at motor level. On the motor's external frame two plates are machined to interface the wheel-set to the rolling chassis (fig.2).

Plates are 9° sloping from perpendicular to wheel axes so steering axis falls in the centre of tire contact area, optimising steering geometry.

This requirement causes the brake to be located at the rear side of the motor. The steering connecting rod is 20° sloping from perpendicular.
Motor frame encloses the motor in two identical shells, one only mould being needed. Between motor and wheel there is a ball thrust bearing as wheel hub (fig 2).
On the external side of the frame there are some cooling fins running around, this has been evaluated as sufficient for motor cooling due to the material of the shells (aluminium).

SOLUTION N°2: UPRIGHT ACTING AS SUBFRAME
For each front wheel an electric brushless AC motor gives power to a single stage gearbox with angular gear (total transmission ratio $\tau=1/5$ and efficiency $\eta=0.97$.).

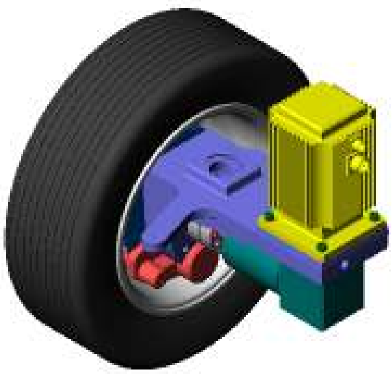


Figure 3

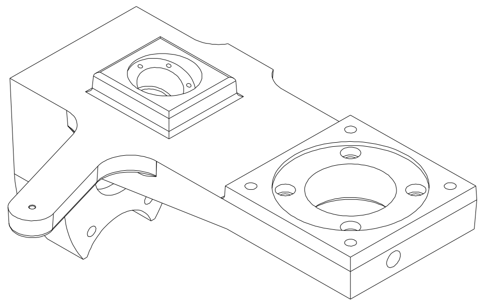


Figure 4

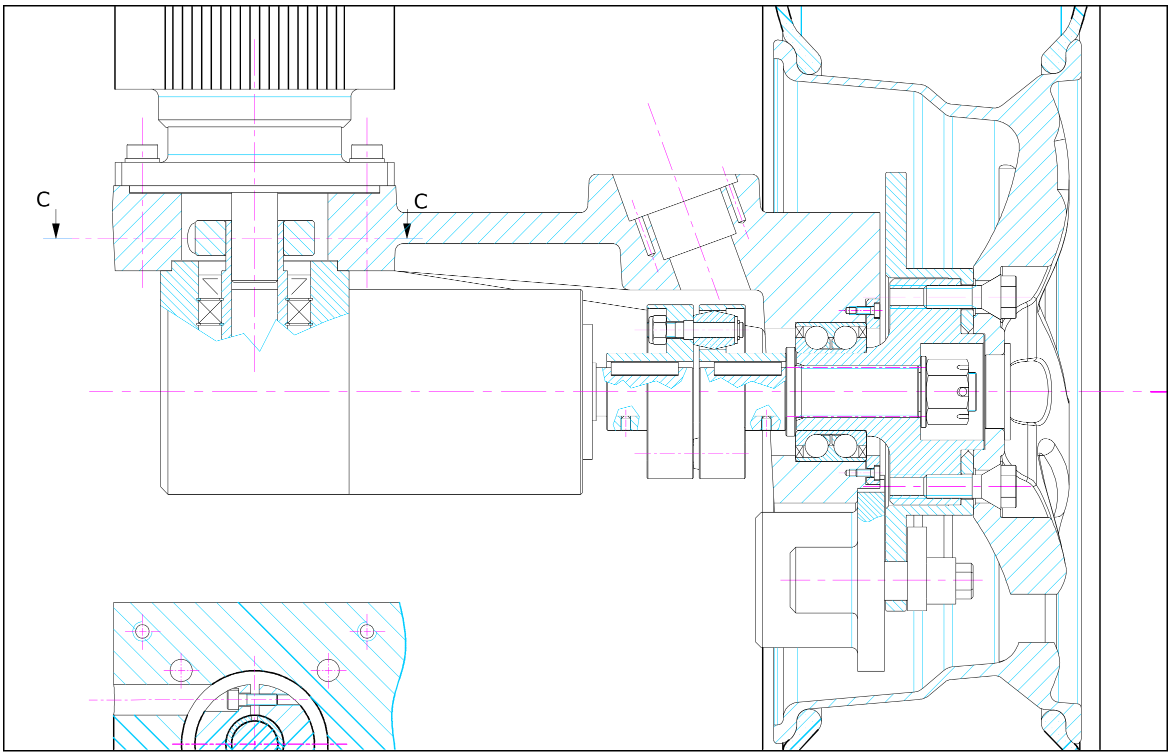


Figure 5

The gearbox output shaft is linked through a rubber spring joint to a geared shaft. This last shaft drives the wheel hub which is linked to disk and wheel (fig.5).
External chassis is made in nodular cast iron in which an automotive ball bearing is inserted (fig 4). This sub-frame is cast in one single shape for right or left application, only some machining being required to differentiate before integration.

The attachment to the car's chassis is 20° side sloping from vertical, as it can be seen in the figure, to have the steering axis passing through the tire contact area. In the machined hole a rotating strut or a thrust ball bearing to couple with car's chassis can be placed (fig.5).
Steering rod is side sloped 17° respect to longitudinal axes to have a maximum wheel steering radium of 45°

SOLUTION N°3: AC BRUSHLESS MOTOR ALIGNED WITH STEERING AXIS

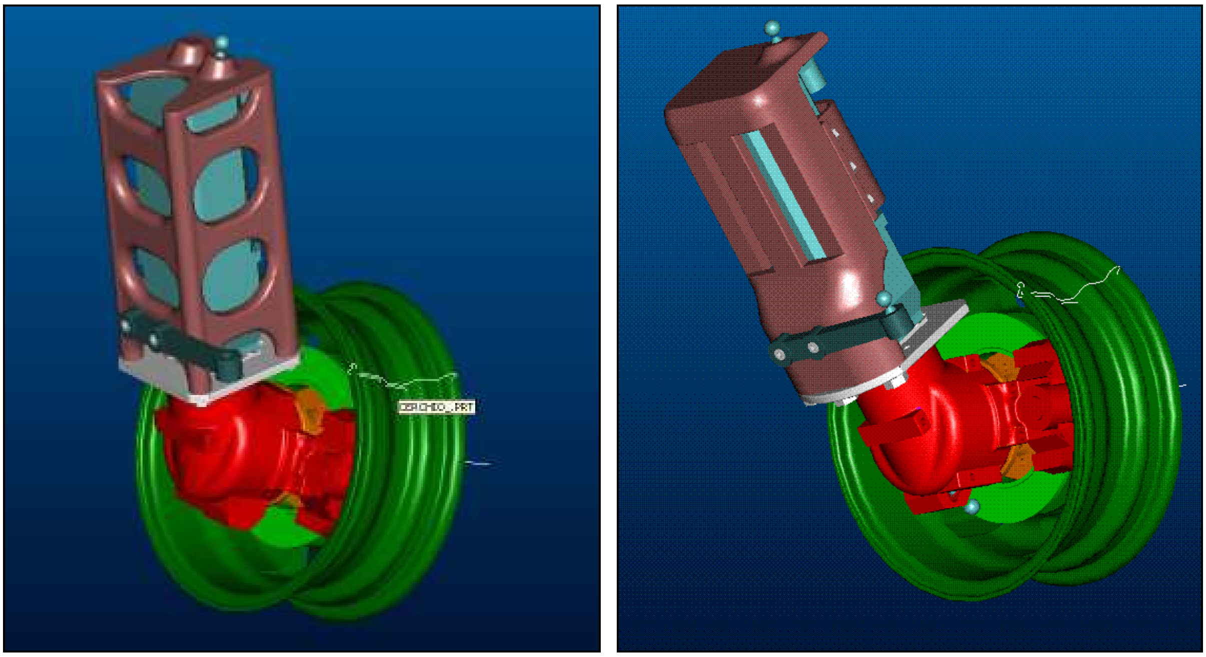


Figure 6

To satisfy project specifications the AC motor sloping was arranged to be parallel (or coincident) with steering axis(fig.6, showing two alternatives). In fact it is necessary to arrange a brace to support motor and wheel sets ball joints. The effects are general weight reduction and steering angle increase, which is very useful in urban environment where this vehicle has to work. This choice involved a complex planning of a bevel gear pair with 25° inclined axes. This gearbox must satisfy automotive components standards, so it must have teeth with *Gleason* profile
The AC motor is linked to the wheel via a Standard Gearbox (from commerce) and a bevel gear pair (built up on drawings), the last with reduction ratio close to 1 (fig.7). The total expected weight is near to 24,9 kg.
Total reduction ratio is allotted between the two gearboxes in order to get a better total efficiency. Moreover it was chosen to keep both reduction ratios less than 1 not to have speed increment in some gear. The commerce gearbox chosen have a transmission ratio close to $\tau = 1/7$ so the bevel gear pair have a transmission ratio of $\tau = 4/5$.Tooth's profile which gives optimum performances was developed by Gleason and named *Duplex Helical*, machined with non standard gear cutters.
Basic size for teeth were the following (table 2):

Sprocket teeth number	18,0
Wheel teeth number	24,0
m	3,0
Shafts angle	115,0
Preessure angle	20,0
Trasmission ratio	0,8
Clearance	0,1

Table 2

Then the *Gleason's computerized calculation,* based on tooth's resistance factor was applied to obtain minimum external diameter compatible with maximum transmitted torque.
The most complex and delicate structural and functional element is the bevel gear pair box. This component, cast in Ergal (Al 7075) and machined, is a support for bearing and carries all loads transmitted from the road to the vehicle suspension system.

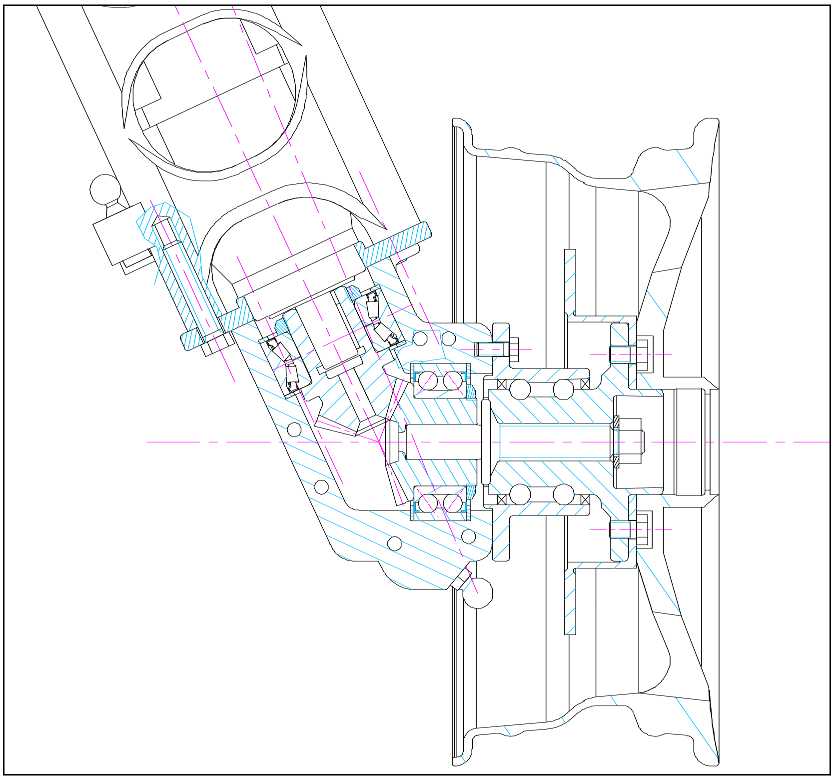


Figure 7

SOLUTION N°4: 90° REDUCTION GEAR WITH CONVENTIONAL UPRIGHT.

This solution was studied to minimise encumbrance. The AC motor attitude is vertical, near the steering axle. The total expected weight is about 22 kg.

With this design the space necessary to the wheel set is reduced with respect to usual solutions. The engine is connected to the wheel hub by mean of a 90° reduction gearbox (fig.8). The upright will be cast in two similar half shelves, only one mould (or models) being needed (fig.9). The steering rod is not integral with the shell, but it will be added on and screw fixed. The threaded holes are symmetrical so it is possible to use a single casting for either the left or the right uprights (fig. 10).

Interface to vehicle chassis is conventional, but it may be substituted by a connection based on ball thrust bearing, with obvious fitting modifications. With the same upright, and proper hole patterns it may be possible to obtain opposite upright.

Figure 8

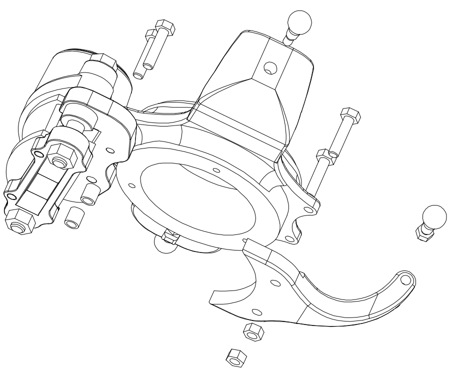


Figure 9

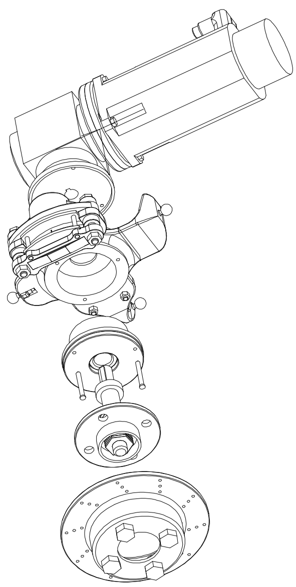


Figure 10

A FEM analysis has been performed on the upright which is the assembly's most stressed element. This study was executed with both a static and a dynamic load sets.
Static case (fig.11) was referred to the vehicle own weight (6000 N), working on the upper joint (properly increased to be conservative)
Dynamic analysis is referred to the stresses induced by common use. To be conservative a maximum load of 8 G's was used. The images refer to the static analysis

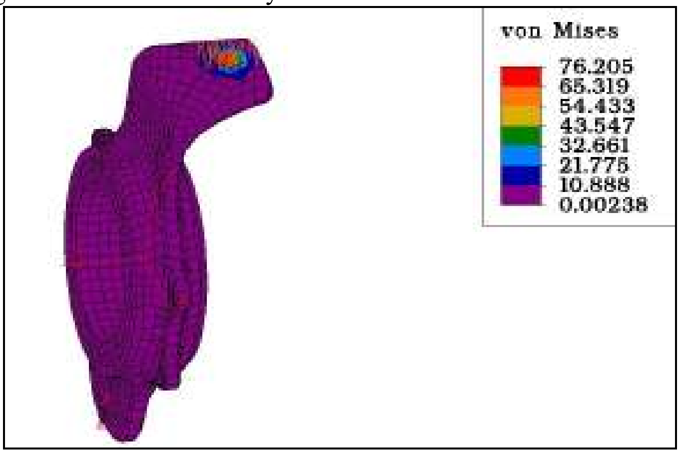


Figure 11

SOLUTION N° 5: VERTICAL STEERING AXIS THROUGH TYRE CONTACT AREA
Traction wheel-set is composed by an AC brushless motor, an epicyclic reduction gearbox and a disc braking system.
All the block is thought to be linked to the vehicle's chassis by the means of a load bearing rigid arm. It was developed a solution lo let a wide choice for the linking system. A plate with a set of six holes to be used for linking was foreseen.
The wheel-set must be assembled to the chassis in vertical attitude as illustrated, in this way the steering axis will be perfectly vertical with a steering radius up to 60° and a steering wheel load very low; the negative aspect is a loss of feedback on tire situation during cornering but it can be admitted in an urban car.
The weight of the entire wheel- set, with rim and tire is expected to be around 45 Kg.

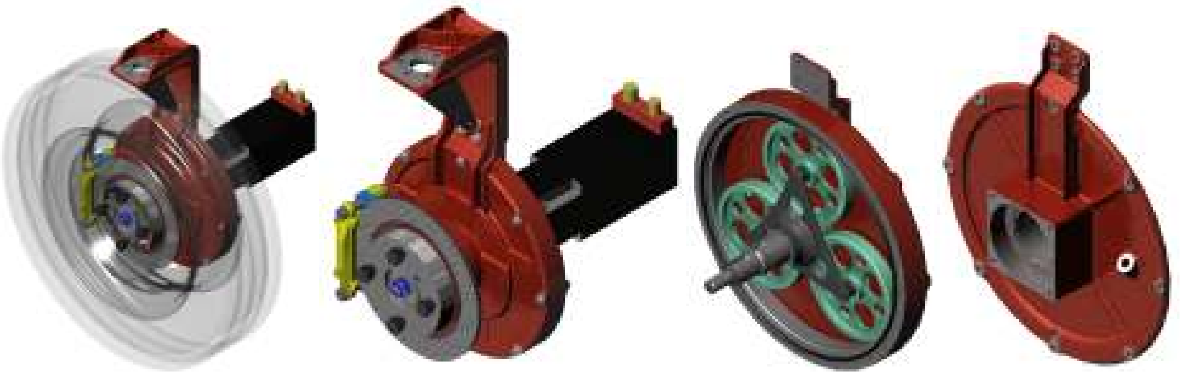


Figure 12
Figure 12 shows a sequence in which it is possible to see the general lay out of the group with load bearing arm (with and without rim and tire), an internal view of reduction gear and the closing cap with oil inlet and outlet screwed holes.
Looking from top during steering action the area overlapped by electric motor can be noted, it is important that car's designer leaves this area free from obstacles. If adequately supported by the car's general lay-out this solution gives minimum steering radius: in fact it is noticeable that the wheels can rotate up to 90° (if allowed by the chassis) and, due to the fact that traction is on the front wheels, the car can rotate with a steering radius quite equal to its wheelbase.
The steering angle was limited to 60°, in order to make use of a conventional steering geometry. Operating the basic data, as like wheelbase, track, rod length and rod attachment position with proper formulas it was proven the feasibility of the required 60° steering angle.
With this solution the vehicle's CIR always stands near the rear axle allowing precise steering operations also at low speed, which is recommended for urban city cars.
Rack, 860 mm long, is posed 255 mm behind wheel axis. Its maximum excursion is ±114 mm. The result is a maximum angle evaluable in 66° with a limit rod angle of 16°.

In figure 13 the general lay-out of the wheel assembly is shown, figure 14 shows a simulation of the wheel-set steering phases with the above-said angles.
The motor is 2,6 KW AC brushless, coaxial to wheel hub; motor maximum rpm are 4500/min , so to obtain a 45 km/h speed it is necessary a reduction gear. The epicyclic gear was chosen for axial encumbrance reduction (remember that it is important to contain area overlapped by motor during steering).

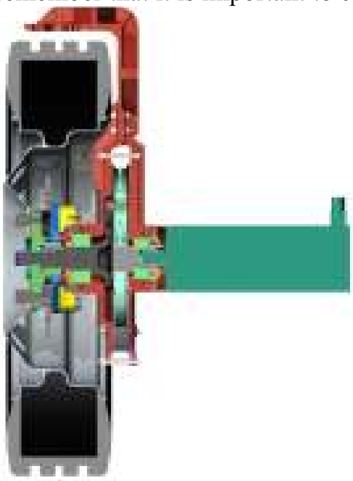


Figure 13

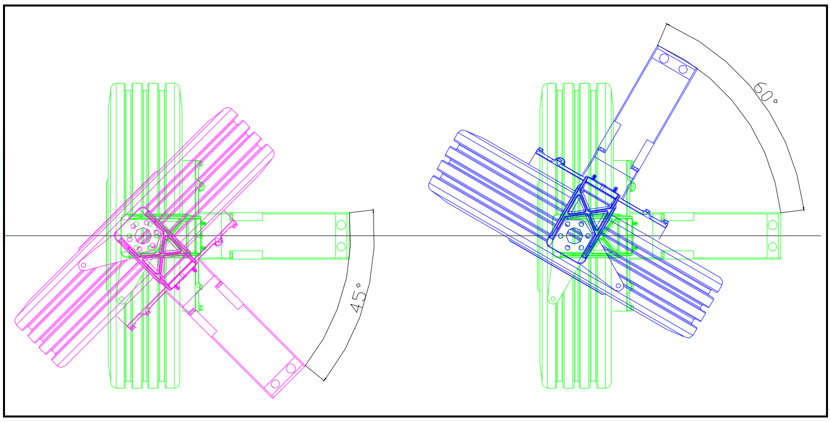


Figure 14

Reduction gear must have external rim fixed, to have a reduction ratio 9:1 in a single stage. Three big planetary gears engaged on central pinion transfer torque to spider which is engaged with rim and tyre.
Spider is the basis on which disc, hub and wheel are assembled; it is supported by a cross ball bearing, sealed type. The bearing seat is located in the cast structure of the load bearing arm.
Oil lubrication is foreseen, proper inlet and outlet screwed holes being foreseen in the model.
Gear enclosing is made by two shells sealed by OR rings.

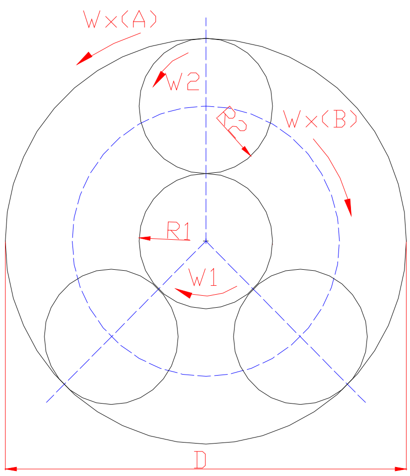


Figure 15

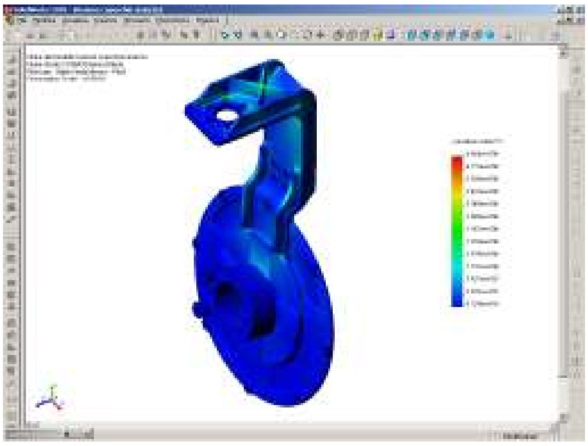
ω1	ω2	R2/R1	D	
			R1=10	R1=15
6000	480	5,25	230	345
4500	500	3,5	160	240

Table 3: Fixed Rim

ω1	ω2	R2/R1	D	
			R1=10	R1=15
6000	480	5,75	250	375
4500	500	4	180	270

Table 4: Fixed Spider

Pinion, external rim and planetary gears pitch lines were calculated to obtain the requested reduction rate. During study phase some different configurations were considered with 6000 and 4500 rpm motors with fixed rim or fixed spider. After some evaluations it was decided to use a system with fixed rim and a 4500 rpm motor (fig.15, tables 3 & 4).
The breaking system is hydraulic with a caliper from "CORAM" catalogue. Designed disc is 209 mm in diameter and 7 mm in thickness.
Some FEM analyses were executed too on load bearing arm. In fact this is the component which bears both weight and dynamic loads. The necessary structural resistance was acquired by use of proper ribs.
In the following images (fig.16 &17) two screenshots from arm analysis are shown; the low level of stresses and their homogeneous distribution can be seen.



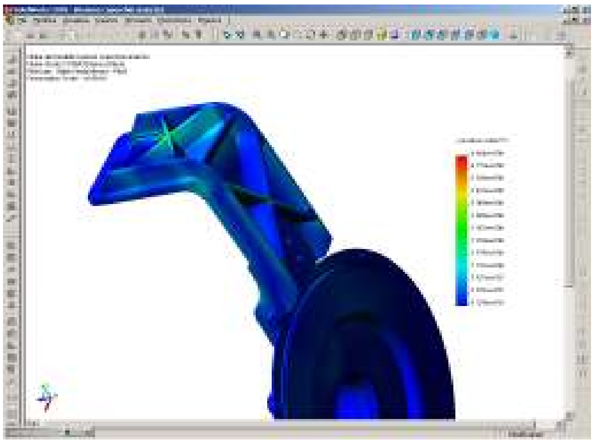


Figure 16 Figure 17

CONCLUSIONS AND FUTURE DEVELOPMENTS

This work has faced the main problems that are encountered in the design of an innovative electric traction set for a light car, proposing some different solutions which can be adopted in every specific case and developing a feasibility study for each of them. However this is just a starting point for the complete design. These group could be considered as „off-the-shelf“ components for everyone thinks to project and develop an electric urban car. Some attention was especially given to aspects like low steering radius and mass reduction of the complete set.
The theme faced in this memory is a chapter of a major work which consist in the development of innovative solutions related to various design aspects involved with city cars.
The major point we intended to underline is that, changing the source of power to the wheels, it is important also to rethink the entire layout of engine-transmission compartment, otherwise it could be quite possible that many potential advantages of electric traction may be lost.
The next step will be to choose the best lay-out between those analyzed and carry it through the developing phase to the executive step (building phase) to be applied on a prototype car.
For the future we intend to apply the same criteria to the design of an electric traction group (with integrated suspension system) for a larger car, a family sedan for example.

REFERENCES

[1] Magnani, P., Cambiaghi, D.,Villa, V.,*"Devices for tetraplegic people: an innovative mechanical system for climbing aboard the driver car seat"*; Tenth World Congress on the Theory of Machines and Mechanisms (IFToMM), Oulu, Finland, June 20–24, 1999.
[2] Cambiagli, D., Faglia, R., Gadola, M., Vetturi, D., Villa, V., Arenghi, A., "On the design of an auxiliary device for disabled people"; IV International Congress of Project Engineering, Cordoba, Spain, 7-9 October 1998.
[3] Cambiaghi D., Gadola M., Uberti S., Villa V., "Morphological Study of Man-Machine Interfaces in a Completely New Type of Car"; 12th ADM International Conference on Design Tools and Methods in Industrial Engineering, Rimini, September 5-7, 2001.
[4] Gandini, D., "Studio di fattibilità per microvettura con sospensioni pneumatiche e modalità d'accesso agevolata", Graduation thesis, University of Brescia, academic year 2004/2005.
[5] Leone, L., Resentera, M., and Chignola, S., "Studio di fattibilità e progetto di una autovettura monoposto da competizione con struttura in lega leggera", Graduation thesis, University of Brescia, academic year 2000/2001.
[6] Copeta, A., "Studio di fattibilità di un veicolo leggero per disabili. Modalità d'accesso e guida", Graduation thesis, University of Brescia, academic year 1999/2000.
[7] Orlandi, G.L., Tomasoni, A., (2004), "Studio, progetto e realizzazione di una vettura da corsa di categoria sport prototipi slalom", Graduation thesis, University of Brescia, academic year 2003/2004.
[8] Guiggiani, M.,(1989), "Dinamica del veicolo",Città Studi Edizioni.
[9] Morelli, A., (2000), "Progetto dell'autoveicolo-Concetti di base", Celid.