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Synchronous Belts Fracture Analysis Using MBS Method

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Abstract

This paper presents a detailed model developed for the characterisation of the behaviour of synchronous belt transmissions, with the final goal of predicting the load distribution on the contact arc and suggesting possible changes, in order to avoid the improper structure of the transmission and the fracture of the belt. CAE methods, such as multi-body analysis aim to replace classical tests after experimental validation of computer software results. This method involves a degree of subjectivity during its deployment: the choice of materials and their properties, the choice of joints and applications, defining areas of contact.

Key words: *synchronous, timing belts, Multi Body System, belts drive.*

Introduction

Belt transmissions are, next to gear transmissions, the most common mechanical transmissions. Belt design and development is based on application tests of belts. This is a need for theory development, designs support systems and would enable simulation for prediction and optimisation of fatigue life.

Belt wear is affected by many factors. Dusty or dirty operating conditions, worn or rough pulleys, shock, loads, insufficient belt tension, pulley misalignment, belt span vibrations and, especially, a high-temperature engine environment can all affect the rate at which a belt will lose performance.

Many of today’s engines use synchronous belts, but not all. Some engines still use a timing chain. Timing belts have all but replaced the timing chain and in doing so have taken on multi-functions. Especially critical with the synchronous belt is uniformity of the teeth and their spacing.

Belts are built to be resilient and flexible. Unfortunately, they are not as durable as metal. After a few years, heat, oil, stress and time take their toll. The belt's inherent tensile or stretch-resistant qualities come from high strength cords that run parallel with the direction of belt travel. Unlike the timing chain the synchronous belt has no stretch ability. The belt’s teeth are precision moulded from a special rubber compound for good mesh and long life [5].

The most used three belt types in automotive transmissions are V-, V-ribbed and synchronous belts (Fig.1). In most cars, belts drive:

- the alternator which supplies electrical power to car;

- the water pump which circulates coolant;
- the fan which draws in air that cools the coolant in the radiator;
- a number of accessories from power steering pumps to air conditioning compressors to air pumps which operate other auxiliary equipment;
- the camshafts, in many new model cars.

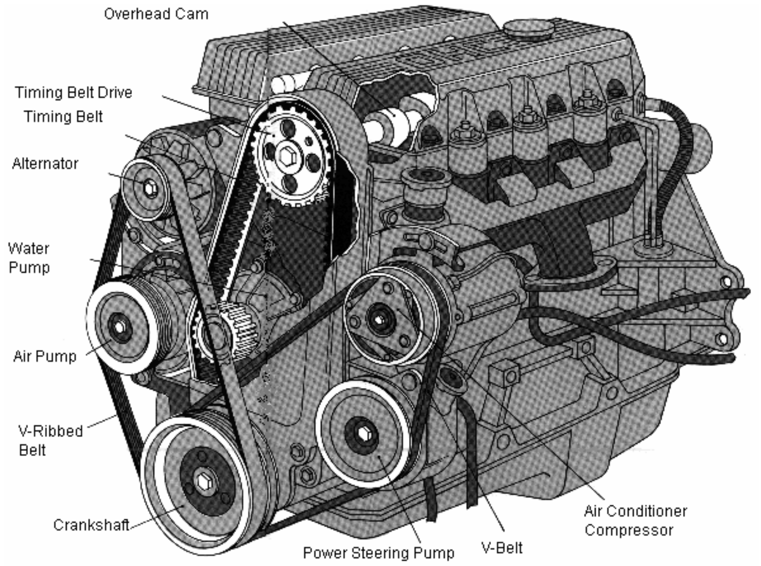

Fig. 1. Automotive engine

The performance and life of power transmission belts has been investigated by a number of research groups over the past decade or so [4].

Synchronous Belts Failure Modes

In a car engine, synchronous belts synchronize crankshaft and camshaft. These belts are superior to metal chains in several respects: reduced noise, no lubrification needed, lighter weight, multi-axle drives [6].

As synchronous belts replace metal chains, certain differences should be kept in mind. Since belts are made of organic materials such as rubber and textiles, special consideration should be given to mechanical load and degradation in ambient temperature [6].

Belt failure can be classified in one of two ways, either through the belt losing the ability to transmit power synchronously or through the belt generating noise to an extent that is unsuitable for the application [4].

Models of belt operation which have appeared in the literature are generally either mechanical models of tooth engagement, finite element models of belt operation, or models of belt vibrational behaviour [4].

Synchronous belts, originally developed with trapezoidal tooth forms, are now developed with curvilinear tooth forms to the stage that their torque transmitting capacity matches that of V-belts of the same size.

Their service life may be limited by:

- wearing away of the protective fabric that covers the rubber teeth and belt land regions;

- tooth root cracking (Fig.2.a);
- failure of the fabric at the tooth roots;
- other mechanism such as separation of the fabric cover from the belt (Fig.2.b);
- failure of the tensile load – carrying cords (Fig.3);
- cracking of the back cover [3].

The tooth root cracking is the prevalent failure mode for synchronous belts and there are two mechanisms for its generation:

- the fatigue and eventual failure of the facing fabric in the tooth root;
- cracking originating in the yarn interfaces in the cord.

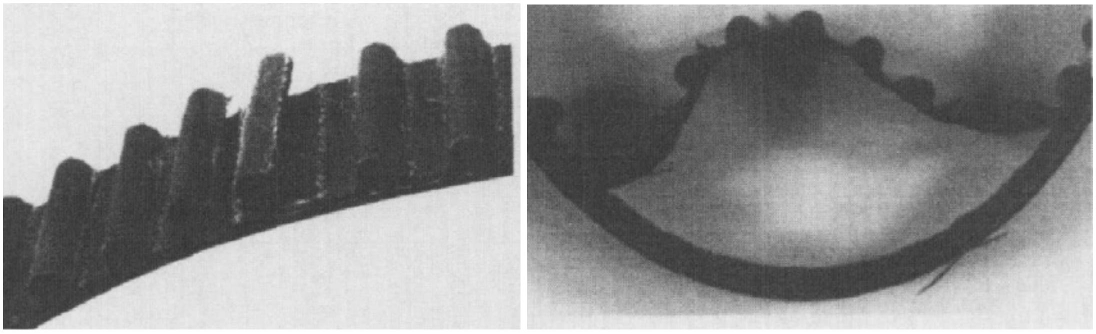
a) **b)**

Fig. 2. Tooth root cracking (a) and fabric separation (b)

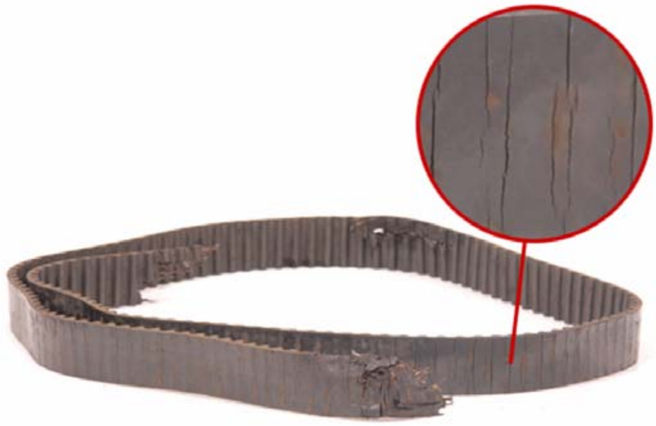

Fig. 3. Broken synchronous belt [1]

Synchronous belt drive

In figure 4 is presented a basic transmission with synchronous belts, which consists in: a driver wheel (1) transmitting the driving torque M_m, a driven pulley (2) with a resistant couple M_r, a tensioner device (3) which produce a pretension force by a linear displacing and a timing belt (4) [2].

The power rating of a synchronous belt drive is determined by a number of variables, including:

1. the strength of the tension members;
2. the shear forces on the face of each tooth;
3. the mating action of the belt and pulley.

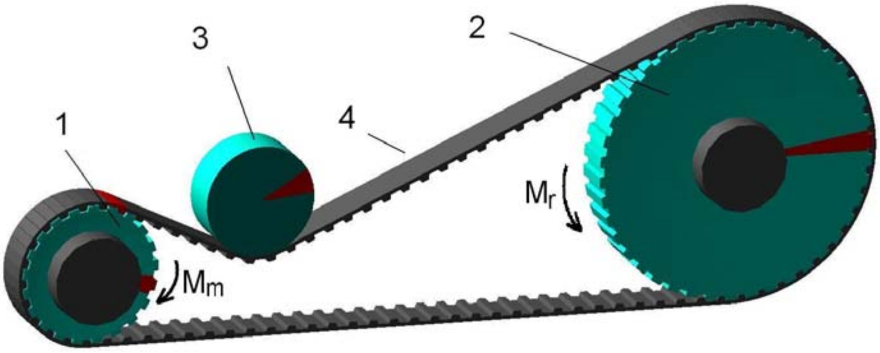

Fig. 4. The basic structure of synchronous belt transmission

The belt Multi-body (MBS) model

The MBS model has been defined as a lumped parameter model, based on a discretization of the belt, to emulate the dynamic behaviour of the transmission.

The model developed includes for each tooth two rigid bodies, each with different properties related to mass and inertia. These two bodies are connecting with rigid couple (Fig. 5).

Spring and rotational constraints to the neighbouring teeth connect each other (Fig. 5), finally forming a belt (Fig. 6). The stiffness of this spring can be easily obtained, because it is mainly due to the properties of the cord that is made of glass fibre.

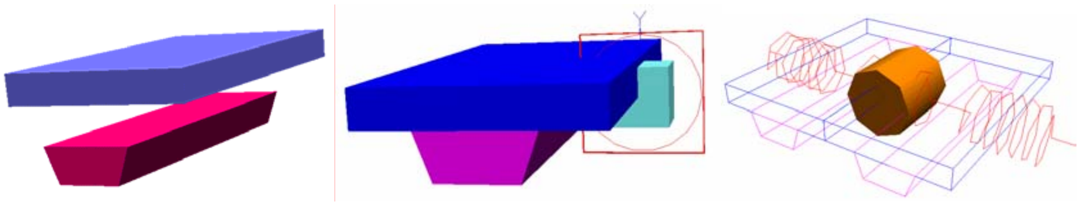

Fig. 5. *Teeth connection and tooth model*

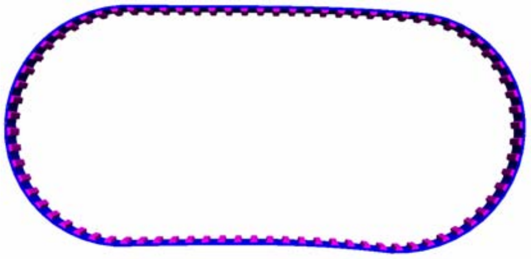

Fig. 6. *The synchronous belt*

The MBS models for pulleys

A rigid body represents each pulley. In order to manage the meshing phase and the polygonal effect, the geometry of the teeth has been duly reproduced. Figure 7 presents the components of a distribution transmission of a FIAT 1300 engine, with 21 teeth sprocket and 42 teeth pulley.

The driving sprocket is connected to the crankshaft, responsible for motion generation. The driven pulley is connected to a camshaft, responsible for brake couple. The Multi-Body model of the transmission is presented in figure 8.

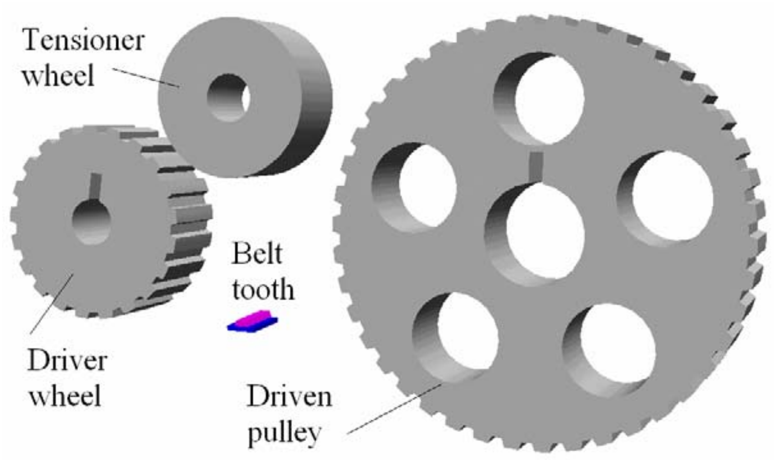

Fig. 7. *The transmissions components*

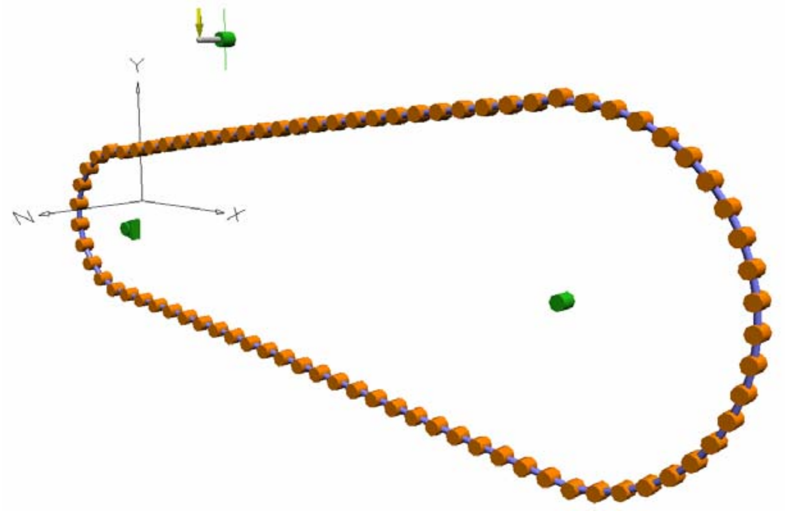

Fig. 8. *The belt drive MBS model*

Multi-body model was run several times on the ADAMS software, changing some parameters. The results presented below are part of a larger set of determinations made on this model. Table below lists a part of the experiments carried out, with the parameters which were modified.

Determination no.	**Angular velocity (grd/sec)**	**Torque (Nm)**	**Tooth stiffness (N/m)**	**Pre-tensioning force (N)**
Det_01	12	20	10^3	200
Det_02			10^4	
Det_03			10^5	
Det_11	12	10	10^4	50
Det_12				200
Det_13				350
Det_21	12	10	10^4	200
Det_22		20		
Det_23		30		
Det_31	12	10	10^4	200
Det_32	24			
Det_33	36			

Tab. 1. *Used experimental values*

The distribution of the teeth loading was measured in the test rig fitted. At the end of dynamic simulation it was possible to obtain detailed information on system behaviour. Figures 9 and 10 have on abscissa the rotation angle corresponding driver or driven pulley, respectively and on ordinate line the values of tooth load.

Figure 9 shows the output of the ADAMS software for the first layout (Det_01…03), when it was modified the teeth stiffness. The equivalent tooth stiffness introduced in a dynamic model permit to give a lot of informative results. Note that, for the driver pulley, with increasing tooth stiffness, the torque will be transmitted by the first teeth come in contact with pulley teeth.

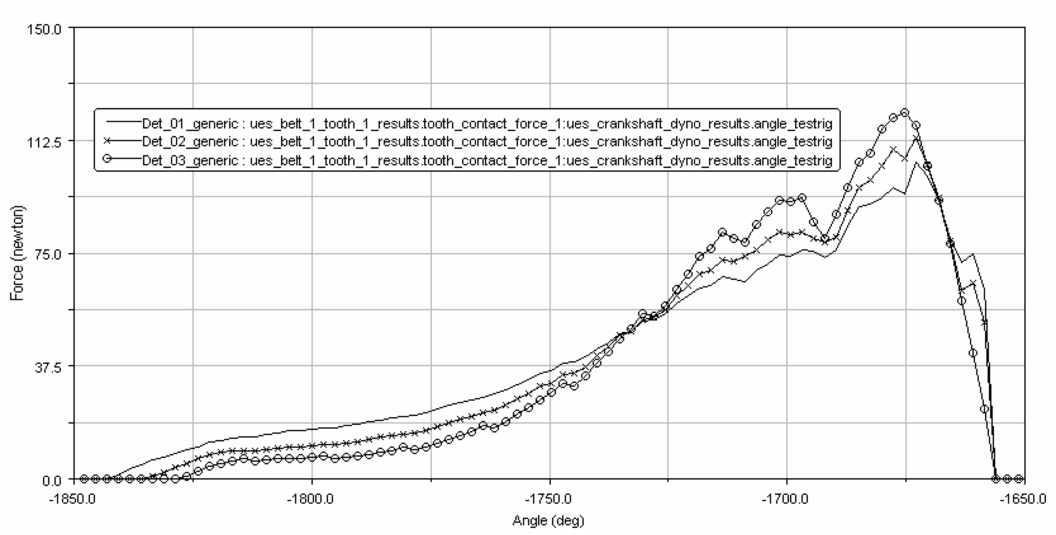

Fig. 9. *Load distribution on driver pulley (cases 01…03)*

Similar results were obtained at the driven pulley, shown in figure 10, were a large part of the torque is transmitted over by teeth being at the end of contact arc, toward the tight side of belt. It may be said that, with increasing teeth stiffness, belt behaviour is closely by chain behaviour.

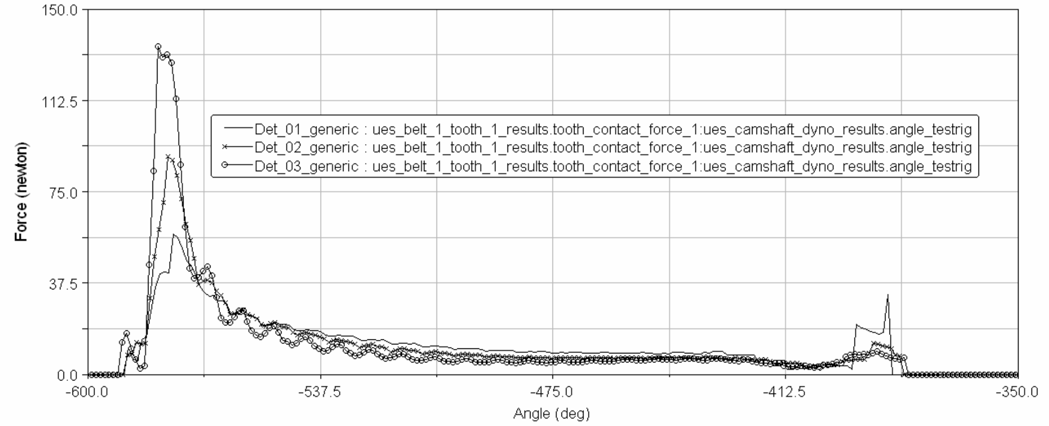

Fig. 10. *Load distribution on driven pulley (cases 01…03)*

Figures 11 and 12 show the same kind of data for the second layout (Det_21…23), with three distinct cases for the brake torque. It can see that for small values of the torque, all the teeth which are in contact with pulley can transmit the torque. Increasing the brake torque, the teeth loading is moving to the tight side of the belt were the belt teeth are much stressed.

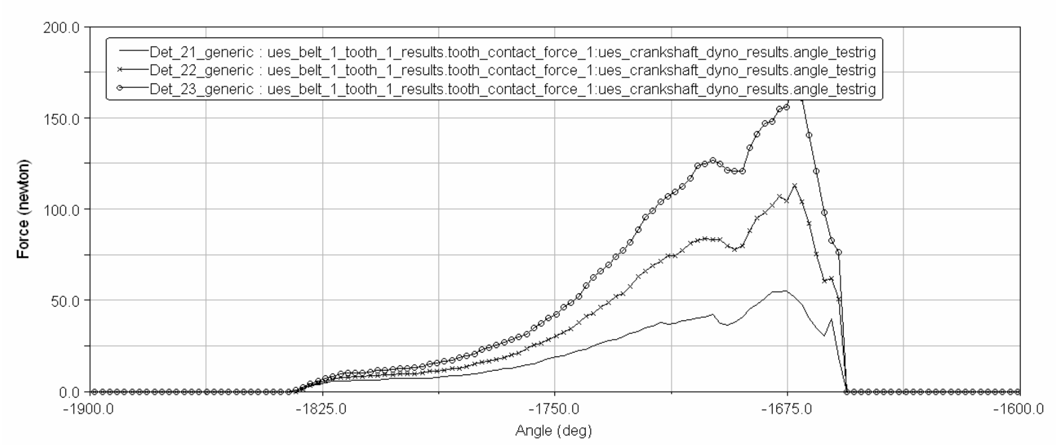

Fig. 11. *Load distribution on driver pulley (cases 21…23)*

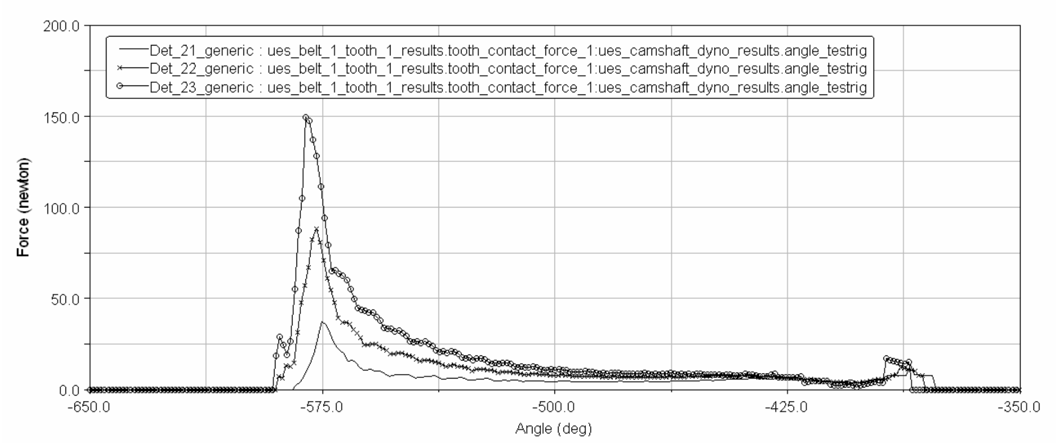

Fig. 12. *Load distribution on driver pulley (cases 21…23)*

Observe how easily it is to upload belt teeth, depending on the position that it occupies at a time by arc of circle. For the teeth, the stress peaks are situated near the tight load side where the tooth load distribution is highest. The maximum loads decrease along the rest of the contact arc in the slack load side [3].

Conclusions

This paper has described a detailed model developed for the characterization of the behaviour of synchronous belt transmissions, with the final goal of predicting the load distribution on the contact arc of a given design and suggesting possible design changes, in order to avoid the improper structure of the transmission.

The presented design method was developed just for these types of situations, when classical methods and available components aren't enough.

The present study has demonstrated the ability of Multi-Body method to simulate the transmission of torque in dynamic regime, between pulleys and belt. In accordance with the results from the simulation operation of a transmission belt by using ADAMS software, it can be said that this type of analysis can lead to getting some interesting results conform to reality, and which excludes the existence of expensive equipment (test rigs, devices, specialized software).

This analysis method involves a subjectivity degree during its deployment: materials and their properties choice, joints and applications choice or defining areas of contact.

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Analiza deteriorării curelelor sincrone utilizând metoda sistemelor multicorp

Rezumat

În cazurile clasice, proiectarea transmisiilor prin curele sincrone implică alegerea componentelor din mai multe cataloage, această metodă bazându-se pe calcule empirice, scopul fiind doar de a satisface condițiile de rezistență şi de cinematică. Pentru cereri speciale, în cazul în care, pe lângă condițiile cinematice şi rezistență, alte tipuri de constrângeri sunt impuse (limite de zgomot, de precizie a mişcării, efectul poligonal...), problema proiectării poate depăşi limitele sistemelor propuse de producătorii de componente. Metoda de analiză prezentată în această lucrare a fost dezvoltată pentru aceste tipuri de cereri, în cazul în care metodele clasice nu sunt suficiente.

Lucrarea prezintă un model detaliat al unei transmisii generice prin curele sincrone dezvoltat pentru analiza comportamentului acesteia, cu scopul final de a prezice distribuirea încărcării dinților de-a lungul arcului de contact dintre curea şi roată. Totodată, în urma simulării este posibilă predicția traiectoriei anumitor parametri de funcționare a transmisiei şi să se sugereze eventuale modificări, în scopul evitării deteriorării elementelor transmisiei. Determinările practice, testele clasice au fost înlocuite prin tehnici noi (CAE - analiza prin metoda multi-corp, MBS), dar doar după validarea experimentală a rezultatelor programelor de calculator. Această metodă implică un grad de subiectivitate în timpul desfăşurării sale: alegerea materialelor şi proprietățile lor, alegerea articulațiilor, definirea zonelor de contact.