Transformation of Gear Inter-Teeth Forces into Acceleration and Velocity*

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(Received 23 April 1998; In final form 10 July 1998)

The paper deals with mathematical modelling and computer simulation of a gearbox system. Results of computer simulation show new possibilities of extended interpretation of a diagnostic acceleration signal if signal is obtained by synchronous summation. Four groups of factors: design, production technology, operation, change of gear condition are discussed. Results of computer simulations give the relation between inter-teeth forces and vibration (acceleration, velocity). Some results of computer simulations are referred to the results obtained in rig measurements and in field practice. The paper shows a way of increasing the expert's knowledge on the diagnostic signal, which is generated by a gearbox system, on a base of mathematical modelling and computer simulation.

Keywords: Gearing diagnostic, Vibration, Computer simulation, Condition factors, Inter-teeth forces

1. INTRODUCTION

Mathematical modelling and computer simulation give new possibilities of investigating the vibration diagnostic signals generated by a gearing of gearbox system for aiding diagnostic inference. In Bartelmus (1994, 1996, 1997), relations between condition of the gearing and inter-teeth forces are given. It comes from that the results of computer simulations were referred to results obtained by measurements presented in Rettig (1977). Because the diagnostic assessment of the gearing condition is taken from vibration measurements, the presented paper is mainly concentrated on relation between inter-teeth forces and vibration parameters like acceleration and velocity. Simulations may be done for any conditions which may change the vibration diagnostic signal. Gear conditions under which investigations were done by Rettig were limited to the change of the operation caused by the change of rotation speed of gears. The gear conditions may be described, as stated in Bartelmus (1992), by four groups of factors: design, production technology, operation, change of gear condition. Many factors will be taken into consideration and results of computer simulations given by the
relation between inter-teeth forces and vibration (acceleration, velocity) will be presented. First mathematical model of a gear system taken into consideration design, production technology, operation and change of condition was given in Bartelmus (1994). The mathematical model is constantly developed and by the use of computer simulations different aspect of gear system dynamics are investigated (Bartelmus, 1996; 1997). The results of computer simulations are referred to the results obtained by a rig investigation (Rettig, 1977) and a field investigation (Bartelmus, 1988; 1992). The results obtained by Rettig (1977) are given in Fig. 1. A dynamic factor giving as a ratio $K_d = F(t)/F$ against a length of line of action, expressed by % of the length, is given. A gear system may run under resonance and over-resonance. The gear system operates at resonance when a meshing frequency equals to a natural frequency of a gearing. Results of computer simulations are given in Figs. 2–4. In Fig. 2 the result of computer simulation is given for the gearing operation under resonance run. It is easy to see similarities obtained by measurements and computer simulations, compare Fig. 1 with Fig. 2, run under resonance. A result of computer simulation when gearing runs at resonance is given in Fig. 3. In Fig. 3 one can see a

![FIGURE 1 Results of measurements of inter-teeth forces (Rettig, 1977).](image)

![FIGURE 2 Function of gearing dynamic factor $K_d$ for under resonance run of gearing (Bartelmus, 1996), $T$ – meshing period.](image)

![FIGURE 3 Function of gearing dynamic factor $K_d$ for resonance run of gearing (Bartelmus, 1996), $T$ – meshing period, $T_n$ – natural vibration period.](image)

![FIGURE 4 Function of gearing dynamic factor $K_d$ for unstable run of gearing (Bartelmus, 1996), $T$ – meshing period, $T_n$ – natural vibration period.](image)
2. MODELLING OF GEARBOX SYSTEM

As it was stated for modelling of dynamic properties of gear system: design, production technology, operation, change of gear condition factors ought to be considered. Design factors include specified flexibility/stiffness of the gear components, especially flexibility/stiffness of a meshing, and a specified machining tolerance and errors of components.

Production technology factors include deviations from specified design factors obtained during machining and assembly of a gearbox.

Operational factors include peripheral speed (pitch line velocity) \( v \) (m/s) and its change \( \Delta v \) (m/s) and load \( F \) and its change \( \Delta F \).

Change of condition includes influences of gear wear, pitting, fractured or broken tooth.
From simulation point of view in the considered
gear system the design factors can be divided into
two groups: constant and controlled. The constant
design factors are not controlled/changed for dif-
f erent simulation experiments. The controlled design
factors are changed before a specified simulation
experiment. The constant design factors are given by:
\( I_s, I_{lp}, I_{2p}, I_m \) – moments of inertia (kg m\(^2\))
(Fig. 7); \( k_1, k_2 \) – shaft stiffness coefficients (Nm/rad)
(Fig. 7); \( \mu \) – coefficient of inter-teeth friction; \( C_h \) –
gearing damping coefficient (Ns/m); \( r_1, r_2 \) – base
radii of gears (m); \( a, b, c \) – parameters of gearing stiff-
ness (0–1) (Fig. 8(a)); \( l \) – inter-teeth backlash \( \mu \mbox{m} \);
\( C \) – maximum value of gear stiffness (N/m),
\( g \) – changeability of gearing stiffness (0–0.4), 0.4
for spur-gear. The controlled design factors are
given by: \( C_s \) – clutch/coupler damping coefficient
(N m s/rad); \( a, e_1 \) – parameters of error function
(Fig. 8(b)); \( l_i \) – random coefficient of error (0–1); \( r \) –
coefficient of error change (0–1), so a value of
an error for a given tooth is expressed by
\[
e = |1 - r(1 - l_i)| e_1,
\]
where \( i \) – number of teeth pair; \( l_i \) is distributed
randomly for \( z_i \) pair of teeth, number of teeth in
the pinion of gears equals to \( z_i \), \( e_1 \) maximum value
of teeth error (\( \mu \mbox{m} \)). The error of teeth may be
described by error mode \((a, e_1; r)\). Mathematical
model for torsion vibration for the system (Fig.
7(a)), is given by equations
\[
\begin{align*}
I_s \ddot{\varphi}_1 &= M_s(\varphi_1) - (M_1 + M_h), \\
I_{lp} \ddot{\varphi}_2 &= M_1 + M_h - r_1(F + F_t) + M_{t1}, \\
I_{2p} \ddot{\varphi}_3 &= r_2(F + F_t) - M_2 - M_{t2}, \\
I_m \ddot{\varphi}_4 &= M_2 - M_e.
\end{align*}
\]
Values of forces and moments are given by
\[
\begin{align*}
M_1 &= k_1(\varphi_1 - \varphi_2), & M_2 &= k_2(\varphi_3 - \varphi_4), \\
M_h &= C_h(\ddot{\phi}_1 - \ddot{\phi}_2)F, & \text{Eq. (4)}, \\
F_e &= C_h(r_1\ddot{\phi}_2 - r_2\ddot{\phi}_3),
\end{align*}
\]
where \( \varphi, \ddot{\varphi}, \dddot{\varphi} \) – rotation angle, angle velocity,
angle acceleration; \( M_s(\dddot{\varphi}) \) – electric motor driven
moment characteristic; \( M_1, M_2 \) – moments of
shafts stiffness; \( I_s, I_m \) – moments of inertia for
electric motor and driven machine; \( M_h \) – damping
moment of coupler; \( F, F_t \) – stiffness and damping
inter-teeth forces; \( M_{t1}, M_{t2} \) – inter-teeth moment
of friction, \( M_{t31} = T_1 \rho_1, M_{t32} = T_1 \rho_2 \),
where \( T_1 \) inter-teeth force of friction (Fig. 7(b)).

Numeric solutions of differential equations are
done by CSSP (Continuous System Simulation
Program) (Siwicki, 1992) by using England pro-
cedure of integration. This is a general procedure of
Runge–Kutta type. The procedure assures stability

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**FIGURE 7** Gearbox system.
of integration even in the case of discontinuity and gives possibility of error estimation and the automatic change of an integration step. Unit CSSPEQ (equation) for inclusion differential equations in PASCAL is used. For example the inter-teeth stiffness force can be written in a form

\[
F := \text{Cs}(\text{pom}, g) \cdot (\max(r_1' y[6] - r_2' y[7] - 1 + \text{Er}(\text{pom}, a, e_1), \min(r_1' y[6] - r_2' y[7] + 1 + \text{Er}(\text{pom}, a, e_1), 0))); \quad (4)
\]

where \(\text{Cs}(\text{pom}, g)\) – stiffness function; \(\max\) and \(\min\) functions are defined as follows:

Function min\((a, b)\) : real;

Begin
if \(a < b\) then min := \(a\) else min := \(b\)
End;

Function max\((a, b)\) : real;

Begin
if \(a > b\) then max := \(a\) else max := \(b\)
End;

\(r_1; r_2\) – gear base radii; \(l\) – inter-teeth backlash; \(y[6] = \varphi_2; y[7] = \varphi_3; \text{Er}(\text{pom}, a, e_1)\) – error function, where \(\text{pom} := \frac{y[6]}{2 \pi} (\frac{z_1}{2}); a, e_1\) – parameters of error function; \(z_1\) – number of teeth in a pinion.

3. RESULTS OF COMPUTER SIMULATIONS

Controlled factors which were changed for investigating their influence to diagnostic signal are: \(C_s\) – clutch/coupler dumping coefficient, \(a\) – parameter of the error function (Fig. 8(b)), and \(r\) – coefficient of error change \((0–1)\), Eq. (1). Obtained results of computer simulation are interpreted like results obtained by synchronous summation of a diagnostic signal. First set of results of computer simulations is given in Fig. 9. Figure 9(a) gives a picture of \(K_d\) function in four different periods: (1) acceleration of a gear system (Fig. 7), from 0 to 980 rpm; (2) free rotation; (3) run of the gear system...
FIGURE 9(a)–(f)
under linear increase of outer moment $M_r$; (4) run of the gear system under constant outer moment $M_r$. Inter-teeth forces are the reasons which cause the failure of a gearing. The inter-teeth force reveals all factors which have influence to vibration generated by a gearbox. The forces are transmitted through bearings to an outer housing. A direction of transmission of inter-teeth forces is given in Fig. 7(b) and lies along a line of action $E_1E_2$. We supposed that if we measure an acceleration on the gearbox housing we may infer on the inter-teeth force's change. It is supposed that the change of the inter-teeth forces is proportional to the difference of acceleration $\Delta_a$ of co-operating gear wheels. The main aim of a computer investigation is presenting differences or similarities between force and acceleration $\Delta_a$. Inter-teeth forces are presented as a ratio $K_d$. Figure 9(b) gives the acceleration difference $\Delta_a$ in four periods. In Fig. 9 results for the error mode $(0.5; 10; 0)$ are given. The error mode function is given in Fig. 8(b). Figure 9(c) gives $K_d$ function in 4th period of a gear system run. In Fig. 9(d) $\Delta_a$ acceleration is given. One can see similarities between Fig. 9(c) and (d). For the same period of time velocity difference $\Delta_v$ is given in Fig. 9(e). There is no direct similarity between inter-teeth force and velocity $\Delta_v$. Inter-teeth force function for 1st period of gearing-co-operation is given in Fig. 9(f). The function shows the period of gearing and the period of natural vibration of gearing $T_n$. The function of acceleration $\Delta_a$ for the 1st period is given in Fig. 9(g). One can see that the error function given in Fig. 8(b) is a cause of two vibration impulses (increase and decrease), so a meshing period $T$ is divided into two periods. It is better seen in acceleration function $\Delta_a$ than in the force function (Fig. 9(f)). Figure 9(c) and (d) does not show full similarity (forces to acceleration), it is supposed that a cause of it is influence of damping moment in the clutch, $M_h$ so for further investigation $C_s = 0$ is taken. Figure 10 gives results of these simulations for condition of $C_s = 0$. Figure 10(a) gives a course $K_d$ function. Compare Fig. 9(a) with Fig. 10(a). In Fig. 9(a) influence of damping moment $M_t$ is seen. Figure 10(b) gives the zoom of $K_d$ course for $C_s = 0$. A zoom course of accelerations $\Delta_a$ presents Fig. 10(c). Figure 10(b) and (e) gives exact similarities of these two courses. Figure 10(d) shows a zoom course of velocity $\Delta_v$ for $C_s = 0$ in the 4th period. Physical quantities of $K_d$ and acceleration $\Delta_a$ for the 1st period are given in Fig. 10(e) and (f), $C_s = 0$. Figure 10(e) shows different main period of a course of $K_d$, compare Fig. 9(f) with Fig. 10(c). Figure 10(e) of accelerations $\Delta_a$ in its course shows a meshing period $T$ of meshing and the gear natural period $T_n$. Figure 11 shows characteristic features of diagnostic signal for an error mode $(0.1; 10; 0)$. Figure 11(a) shows an error mode function. Figure 11(b) and (e) shows zooms of inter-teeth forces for 4th and 1st period. Figure 11(d) and (f) shows zooms of acceleration $\Delta_a$. The error mode $(0.1; 10; 0)$ is thought to describe new gearing before run in or at the condition change caused by failure of one bearing supporting gear wheels. At the condition of bearing failure value of $e$ increases either. Compare different courses given in
FIGURE 10  (a) Function of gearing dynamic factor $K_d$, clutch damping $C_s=0$. 1 – period of acceleration of gear system from 0 to 980 rpm, 2 – period of free rotation, 3 – period of run under linear increase of outer moment, 4 – period of run under constant outer moment. (b) Zoom of $K_d$ for $C_s=0$, stable run of gearing under steady load, 4th period. (c) Zoom of gearing circumference acceleration $\Delta_a$ for $C_s=0$, 4th period. (d) Zoom of gearing circumference velocity $\Delta_v$ for $C_s=0$. (e) Zoom of $K_d$ for $C_s=0$, unstable run of gearing during increasing rotation, 1st period. (f) Zoom of gearing circumference acceleration $\Delta_a$, $C_s=0$, 1st period.
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FIGURE 11  (a) Gear error function for error mode \((a; e; r)\) (parameter of error function; maximum value of error; coefficient of error change), \((0.1; 10; 0)\). (b) Zoom of inter-teeth force, parameter of error function \(a = 0.1\), stable run of gearing under steady load, 4th period. (c) Zoom of gearing dynamic factor \(K_d\) function \(a = 0.1\), 4th period. (d) Zoom of gearing circumference acceleration \(\Delta a\), \(a = 0.1\), 4th period. (e) Zoom of inter-teeth forces, \(a = 0.1\), 1st period. (f) Zoom of gearing circumference acceleration \(\Delta a\), \(a = 0.1\), unstable run of gearing during increasing rotation, 1st period.
Figs. 9(g) and 11(f). The meshing period in Fig. 9(g) is divided into two equal parts \( (a = 0.5) \) in the error mode, in Fig. 11(f) the machine period is divided in different ways \( (a = 0.1) \) in the error mode. Deterioration of a gearing causes random change of error function. A depth of error change for simulation of this condition is given by an error mode parameter \( r \). Current error is given by Eq. (1). Error functions for \( r = 0.1; 0.3; 1 \) are given equivalently in Fig. 12(a), (d) and (h). In Bartelmus (1997)
FIGURE 12. (a) Error mode function for \((0.5; 10; 0.1)\), \((a, e, r)\) (parameter of error function; maximum value of error; coefficient of error change). (b) Gearing circumference acceleration function \(\Delta_a\) for coefficient of error change \(r = 0.1\), stable run of gearing under steady load, 4th period. (c) Function of acceleration dynamic coefficient \(A_d\) for \(r = 0.1\), 4th period. (d) Error mode function for \((0.5; 10; 0.3)\). (e) Gearing circumference acceleration function \(\Delta_a\) for \(r = 0.3\), 4th period. (f) Function of current dynamic factor \(K_d\) for \(r = 0.3\), 4th period. (g) Function of \(A_d\) for \(r = 0.3\), 4th period. (h) Error mode function for \((0.5; 10; 1)\). (i) Gearing circumference acceleration function \(\Delta_a\) for \(r = 1\), 4th period. (j) Function of \(A_d\) for \(r = 1\), 4th period. (k) Gearing circumference velocity function \(\Delta_v\) for \(r = 1\), 4th period.
some new normalised functions for evaluation of
gearing conditions were discussed. The most suit-
able function was chosen defined as $K_{d1} = F(t)/F_l(t)$, where $F_l(t)$ – measured current force on an
input shaft of a gearbox. But for practice there is
a need to define equivalent function based
on acceleration which are measured on a gearbox
housing. For the new condition measure next value
is defined as

$$A_d = \left[ A + (\Delta_a) r_1 \right]/(M_1 + M_h),$$  \hspace{1cm} (6)

where $A_d$ – normalised gearing condition function;
$A$ – suitable constant to make the value positive;
$\Delta_a$ acceleration; $(M_1 + M_h)$ moment on the first
shaft; $r_1$ – radius of a pinion gear. $A_d$ function is
given for $r = 0.1; 0.3; 1$ in Fig. 12(c), (g) and (j). An
example of a function of $K_{d1}$ is given in Fig. 12(f)
for $r = 0.3$. Acceleration functions $\Delta_a$ are given for
$r = 0.1; 0.3; 1$ in Fig. 12(b), (e) and (i). One example
of a course of velocity function is given in Fig.
12(k) for $r = 1$. On a base of simulations given in
Fig. 12, a conclusion is drawn that $A_d$ function is
very good parameter for condition change identi-
fication of a gearing. One of the most important
thing in condition monitoring is identification of a
fractured or broken tooth. Figure 6 shows a local
change of the signal, for one broken tooth one
local change of a diagnostic signal. So we may say
there is one-to-one mapping. Another evidence for
this is given in Fig. 9(g) where a decrease and an
increase of a tooth error (Fig. 8(b)) are identified
by one impulse in a diagnostic signal. But for an
error shape given in Fig. 11(a) an identification of a
decrease and an increase of a tooth error is not
so clearly identified (Fig. 11(e) and (f)). Taking in
mind possibilities of one-to-one identification,
further simulation experiments were undertaken.
Figure 13 gives a set of results of simulation for
one fractured tooth for which a stiffness fall to
0.68 of its normal stiffness. As it is seen from the
results of simulation there is very little change of a
diagnostic signal given by $K_{d1}; \Delta_a; K_{d1}$ (Fig. 13(a)–
(c)). Results of further simulations when stiffness
of one tooth in gearing falls to 0.25C are given in
Fig. 14. Figure 14 gives a set of results of computer
simulations for stiffness change to 0.25C. The results show that the change of stiffness to 0.25C gives change of diagnostic signal which may be easy to identify. For further stiffness change to 0.075C results are given in Fig. 15. In Fig. 15(a) and (b) one can see one-to-one mapping (one disturbance in the signal one fractured tooth). In Fig. 15(c) it is seen that one fractured tooth may cause disturbance on several teeth, so there is no one-to-one mapping. It may be stated that $A_d$ function defined by Eq. (6) is very sensitive to condition change but for heavy fracture of a tooth function may be too sensitive. A set of simulation results for a broken tooth is given in Fig. 16. The set presents the equivalent zoom functions for $K_d; \Delta_d; K_{d1}$. Fig. 16(c) does not show one-to-one mapping. Figure 17 gives a set of results of

![FIGURE 14](image1.png)

![FIGURE 15](image2.png)

FIGURE 14 (a) Zoom of dynamic factor $K_d$ for stiffness change to 0.25C. (b) Zoom of gearing circumference acceleration function $\Delta_d$ for gearing stiffness change to 0.25C. (c) Zoom of current dynamic factor $K_{d1}$ for gearing stiffness change to 0.25C.

FIGURE 15(a) and (b)
4. CONCLUSIONS

From the results of computer simulation which are considered as diagnostic signals obtained from synchronous summation detailed features of the signal may be drawn. For example on the basis of results presented in Fig. 2 one may draw a conclusion that an error shape of a tooth taken for investigation by Rettig (see Fig. 1) is as it is given in Fig. 8(b). The same conclusion may be drawn from Fig. 10(c) which gives a diagnostic signal in form of acceleration. From Figs. 9(d) and 10(c) one may draw a conclusion that not only properties of a gearing but also the damping properties of a coupling between an electric motor and a gearbox have influence on a diagnostic signal. One-to-one mapping (one fault one disturbance, in a signal, equivalent for one tooth) does not always hold (see Figs. 15(a) and 16(c)). It seems that this drawback may be eliminated by careful study of evolution/
FIGURE 17  (a) Error function for one pitted tooth. (b) Zoom of gearing circumference acceleration function for one pitted tooth. (c) Zoom of dynamic factor $K_d$ function for one broken tooth. (d) Function of current dynamic factor $K_{dl}$ for one pitted tooth. (e) Zoom of gearing circumference acceleration function $\Delta a$. 

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development, of a diagnostic signal, as gearing condition changes to avoid misinterpretation. Deterioration of a gearing is described by a change of condition for all teeth in a gearing, models of error modes are given by Fig. 12(a), (d) and (h), and for a single fault, as pitting in one tooth (Fig. 17(a)). The best results of diagnosing the gearing condition change are obtained for signal of acceleration which gives direct measure of inter-teeth forces when a gearbox system runs in steady condition, 4th period of Fig. 9(a). New gearing condition parameter is suggested, the parameter is denoted as \( A_d \) and is given by the formula (6). Mathematical modelling and computer simulation is a very good tool for supporting diagnostic inference. Visualisation of diagnostic signals obtained by computer simulation extends knowledge of a diagnostic expert. The presented results show that from signal presented by synchronous summation it is possible to draw many conclusion on gearing condition not only a broken tooth condition.

**NOMENCLATURE**

- \( a \) parameter of error function; parameter of gearing stiffness
- \( A_d \) acceleration dynamic coefficient
- \( b \) parameter of gearing stiffness
- \( c \) parameter of gearing stiffness
- \( C, C_{sz} \) gear stiffness, stiffness function (N/m)
- \( C_h, C_s \) damping coefficients (N m s or N s/m)
- \( e, e_1 \) parameters of error function
- \( \dot{e} \) error function
- \( g \) parameter of gearing stiffness
- \( F, F_1 \) stiffness and damping inter-teeth forces (N)
- \( I_s, I_{1p}, I_{2p}, I_m \) moments of inertia (kg m²)
- \( k_1, k_2 \) shaft stiffness coefficients (N/m)
- \( K_d, K_{d1} \) dynamic coefficients
- \( l \) inter-teeth backlash (μm)
- \( l_i \) random coefficient of error
- \( M_1, M_2 \) moments of shaft stiffness (N m)
- \( M_{te1}, M_{te2} \) inter-teeth moments of friction (N m)
- \( r \) coefficient of error change
- \( r_1, r_2 \) base gear radius (m)
- \( T \) inter-teeth friction force (N)
- \( \mu \) coefficient of friction
- \( \Delta_{at}, \Delta_v \) acceleration and velocity function (m/s² and m/s)
- \( \varphi_1, \varphi_2, \varphi_3, \varphi_4 \) rotation angels (rad)
- \( \dot{\varphi} \) angle velocity (rad/s)
- \( \ddot{\varphi} \) angle acceleration (rad/s²)
- \( \rho_1, \rho_2 \) radius (m)

**References**

Bartelmus, W. (1988) Diagnostic of bevel and cylindrical gears in surface mines, Proceedings of the Second International Symposium on Continuous Surface Mining, Austin, Texas, October 1988, A.A. Balkema Rotterdam, Brookfield, pp. 131–144.

Bartelmus, W. (1992) Vibration condition monitoring of gearboxes, Machine Vibration, 1, pp. 178–189, Springer-Verlag London Limited.

Bartelmus, W. (1994) Computer simulation of vibration generated by meshing of toothed wheel for aiding diagnostic of gearboxes, Conference Proceedings Condition Monitoring ’94, Swansea, UK, pp. 184–201, Pineridge Press, Swansea, UK.

Bartelmus, W. (1996) Diagnostic symptoms of unstability of gear systems investigated by computer simulation, Proceedings of 9th International Congress, COMADEM 96, Sheffield, pp. 51–61.

Bartelmus, W. (1997a) Visualisation of vibration signal generated by gearing obtained by computer simulation, Proceedings of XIV IMEKO World Congress, pp. 126–131.

Bartelmus, W. (1997b) Influence of random outer load and random gearing faults to vibration diagnostic signals generated by gearbox systems, Proceedings of 10th International Congress; COMADEM 97, pp. 58–67.

Penter, A.J. (1991) A practical diagnostic monitoring system, Proceedings of an International Conference on Condition Monitoring, Erding, Germany, Pineridge Press, pp. 79–96.

Rettig, H. (1977) Innere Dynamische Zusatzkräfte bei Zahnerzeugen, *An. Antriebstechnik*, 16(11) (1977), pp. 655–663.

Siwicki, I. (1992) Manual for CSSP (in Polish) WARSAW.
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