Problems by Constructional Engineering of the Supply Transformers

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Abstract - **The designed programming product is comformable to the materials used in Bulgarian transformer production and it optimizes the transformer construction for a definite operation mode and regimes of exploitation. It is considered that the criteria of optimization of the transformer are different and even conflicting for different types of electronic equipment to be installed.**

Index Terms - **supply transformer, mains transformer**

I. INTRODUCTION

Construction of a supply transformer (ST) is a responsible task. Its purpose is to cope with the important problems, connected with: minimal values of mass, heating losses, voltage-drops, etc. For example, if there is a requirement for minimal cost, the price of the conductors (copper) is higher than the price of the magnetic core (silicon steel) and it becomes necessary to increase the dimensions and the mass of the core and hence the dimensions and the mass of the whole ST. If the transformer must be with the minimal mass and dimensions we have to increase the induction in the core and the current density in the windings.

All these changes require increasing the temperature of the ST and reducing its coefficient of efficiency. On the other hand, in order to decrease the section of the core it is necessary to increase the dimensions of its window and to increase the number of the turns in the windings. However, the increase of the number of the turns in the windings is followed by the increase of the cost of the ST. Obviously, the requirements for dimensions, mass and cost of the transformer are conflicting and its optimization is not a trivial task. Defining one of these requirements as a prior one is compulsory. This choice influences the construction of the ST

II. ALGORITHM FOR CONSTRUCTIONAL ENGINEERING OF THE TRANSFORMER

Constructing the ST is a mathematically indeterminate task – the input data are not enough to define all the parameters of the transformer. It necessitates some parameters to be selected in the program at the first stage – on the basis of the a priori theoretical and empiric information.

Therefore a priori data are intentionally loaded in the program in the form of arrays: data about the parameters of the enameled thermostable conductors of the type ПЕТ1 and ПЕТ2; voltage- drops in the primary and secondary windings at different values of the power of the ST; recommendable thickness of the dielectrics between the windings, between the rows and the material of the spool; parameters of the standard lamella E-shaped cores with normalized dimensions and minimal weight and volume; parameters of the standard ribbon E- and П-shaped cores

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The input data are about: the specific losses in the ferromagnetic material for different sorts of steel and different standard thickness of the sheet at fixed values of the magnetic induction; the current density in the windings and the magnetic induction in different types of cores at different ST power, etc.

Caused by the first tentative selection of parameters, some check computations are compulsory performed in the program in order to compare the received results with the prescribed parameters. At discrepancy between the results and the given parameters a correction of the selected values is being done till the parameters of the designed ST reach the permissible limits.

Knowing that the lower the voltage supply frequency and the power of the transformer, the slighter the influence of the released heat during its dimensioning and the more significant the restrictions of the voltage-drops in the windings. An important factor in selecting the construction for the transformers with high power and high voltage supply frequency is the value of the inevitable losses of power in the ST that lead to the transformer heating as well as to the inevitable voltage-drops causing the instability of the initial voltage.

The requirements for achieving the minimal voltage-drops in the windings and minimal heating are conflicting. To reduce the voltage-drops means to increase the section of the conductors in the windings and the dimensions of the core window. It is necessary to decrease the number of the turns in the windings. But it makes the operating mode worse and is often followed by a significant increase of losses in it. That is why the ST construction and its electrical parameters are defined by the fact which of these factors are presented (in the main menu) as priority ones.

Throughout the designing of the program the following conclusion is taken into consideration: the transformer with maximum coefficient of efficiency is not always the most suitable for the electronic equipment because of its big dimensions, mass and cost. Fig.1 shows the program algorithm and Fig.5 - the details of the program.

III. PROGRAM FOR CONSTRUCTIONAL ENGINEERING OF THE TRANSFORMER

The value of the specific losses of magnetic energy in sheet steel depends on the temperature, the frequency of magnetizing current and its mark. In this case if we increase the level of doping with silicon, the losses of magnetic energy in the steel will reduce. On condition that all of the dimensions are equally to the both steels, these losses in the cold rolling steel will be less than ones in the hot rolling steel.

The first level of the program is connected with choosing a steel and a thickness of the sheet – the dimensioning starts with the Э310 or a hot rolling one Э42 steel (steels with the lowest cost) and the thickness of the steel sheet – 0,5 mm (if there is a requirement for the lowest cost) or 0,35mm (if there is a requirement for minimal dimensions) [2].

If the frequency of the supply voltage is 400Hz, the program continues with choosing an appropriate material for magnetic core. For this purpose, it is used either a cold rolling electrotechnical steel Э340 or a hot rolling one Э44.

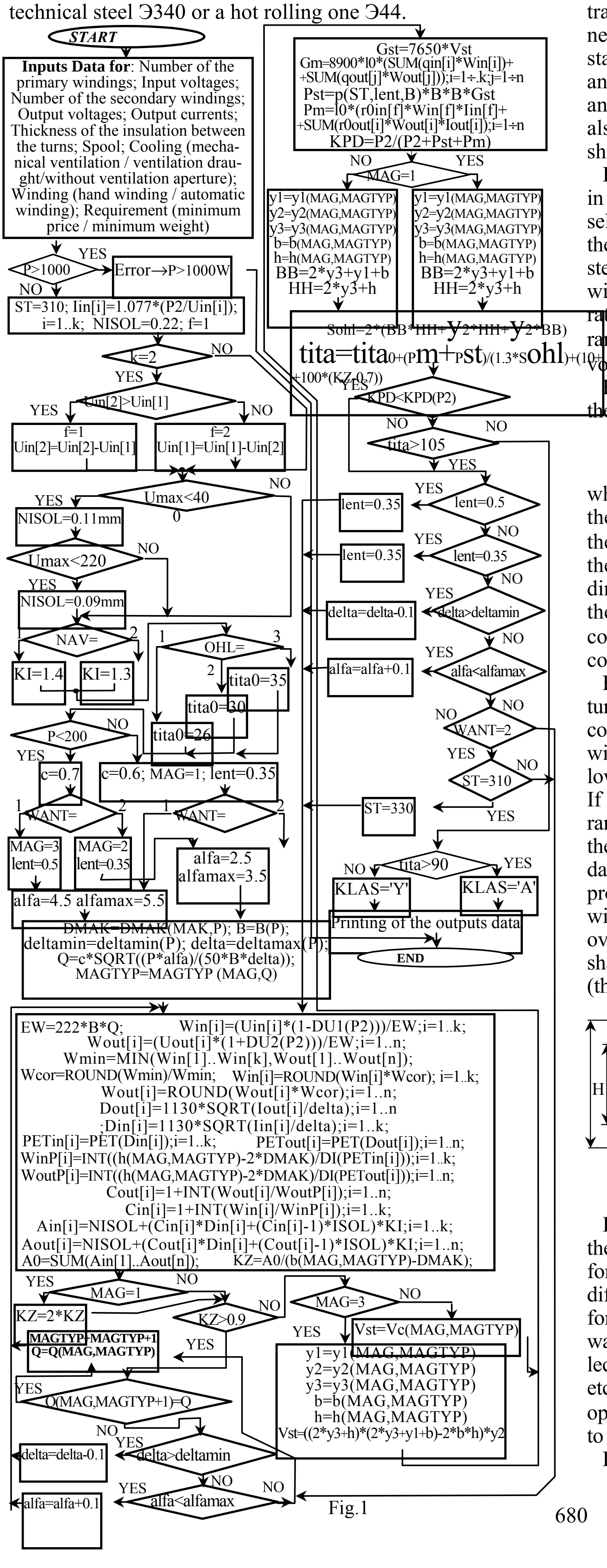

Fig.1

In order to produce magnetic cores for маломощни supply transformers that work with frequency 400 Hz or more, it is necessary to use the hot rolling steel Э44 that is usually with standard thickness of the sheets: 0,2mm, 0,15mm, 0,10mm, and rarely (for higher frequencies) – with thickness: 0,08 mm and 0,05 mm. Besides this type of steel, in the procedure can also be used the cold rolling steel Э340 with thickness of the sheets - 0,2 mm.

It is computed the active and reactive components of the currents in the primary side and the typical power. After that the program selects values of the induction in the core, the current density in the windings and the suitable mass correlation a between the steel (core) and the copper (windings). The optimization starts with a selection of the maximum value (from the permissible rating) of the current density and the minimal value of a (in the range 2,5÷3,5 if there is a requirement for minimal weight and volume and 4,5÷5,5 if there is a requirement for minimal cost).

By the help of the selected values and Arnold's formula [1] the optimal section of a definite transformer is calculated:

$$S_{CT} = C\sqrt{\frac{P_T.\alpha}{f.B_m.\Delta}}\ , [m] \qquad (1)$$

where C=0,7 or C=0,6 is coefficient, whose value depends on the shape of the magnetic core; P_T, W – the average power of the transformer; α - weight correlation between the mass of the steel (at the magnetic core) and the copper (at the winding); f, Hz – the frequency of the supplying voltage; B_m, T the amplitude value of the magnetic induction at the magnetic core; Δ, A/m^2 – average value of the current density at the conductor of the winding.

Fig.2 shows the power from 1 to 200W of the algorithm that is turned to the arrays containing data for the Ш-shaped magnetic cores. The spiral Ш-shaped cores compared to the cores filled with lamella have lower currency at idle running, lower losses, lower weight and dimensions and they are more technological. If there is a requirement to provide these parameters, the program works with the data array for the spiral Ш-shaped cores. If there is a requirement for a low cost the algorithm turns to the data file for the Ш-shaped cores. For powers below 1W the program works with the data array for the П-shaped cores with windings, mounted on one of the branches (Fig. 3). At power over 200W the program works with the data array for the П-shaped cores but the windings are placed on the both branches (the cooling surface of the windings is extended).

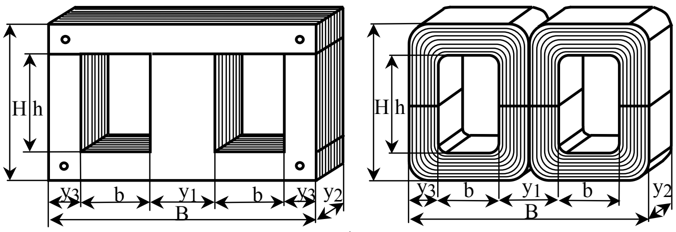

Fig. 2

If the specific power of the transformer is higher than 1000W, the program shows a message for an error. The methodology for dimensioning the transformers for lower power (to 1000W) differs from the methodology for dimensioning the transformers for higher power (over 1000W). Their difference is due to the way of calculating the currents in the primary winding, the selected induction in the core, the voltage-drops in the windings, etc. The methodology after which the program is developed is optimal for low power – to 400÷500W but its usage for power to 1000W provides good results.

Examining curve 1 on Fig.4 we can read the current density

Δ [A/m²] when the frequency of the supply voltage is 400Hz. A part closed between curves 2 and 3 gives information about the current density when the frequency of the supply voltage is 50Hz. Reading of the current density from Fig.4 is tentative. In the first steps of the examination the density is accepted as equal to each of the windings. Designing finishes with check of the thermal conditions of the ST. If temperature of worming is too high (if the the losses in the copper are high), it is chosen a conductor with bigger section (bigger diameter):

$$d_i = 1{,}13\sqrt{\frac{I_i}{\Delta}} \qquad (2)$$

In order to build the process completely, the program offers the operator the most suitable sort and thickness of the dielectrics for the spool, the insulation between the windings and the turns, if during the entering of the initial data the dielectrics are not shown. If the operator does not enter this information, the program chooses and works with the most suitable dielectric materials and their thickness.

If the winding space factor for the window of the core is impermissible high (K_3>0,9) the algorithm selects another core with bigger window dimensions but with the same section. If there is not such window in the data file for standard cores the program reduces the current density with 1 (10 Δ but Δ resupply in the allowable range) and increases the value of the weight coefficient α, (but α remains in the permissible range). Thus the core section increases in a way that a new core with bigger dimensions can be selected.

In the program files are written the data about the volume of the core V_{St} for spiral cores but for the lamella cores these data are absent. That is why the program calculates V_{St} considering the fact that the steel takes about 88% of the geometrical dimensions of the core.

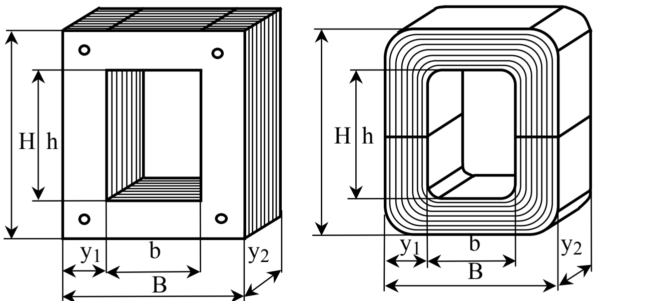

Fig. 3

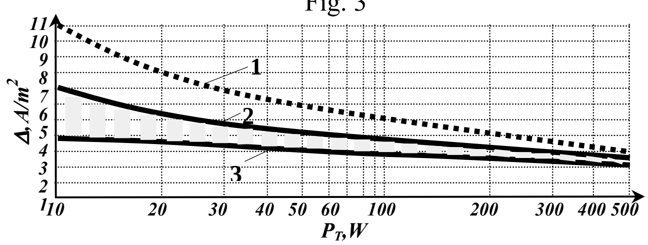

Fig. 4

It is also given some information about the program checkups of the real values of the weight coefficient α, losses in the windings P_M and losses in the core P_{St}, the coefficient of efficiency and the maximal temperature. The permissible transformer temperature is to 105°C and this is the maximal temperature of the insulating materials of the spool, between the windings and between the turns in the windings. For temperature values below 90° C the program selects isolating materials with a heat resistance class Y.

At receiving the coefficient of efficiency below the recommendable values (for a corresponding power) or a higher heating temperature, the algorithm looks for opportunities of reducing P_M and P_{St}. It is achieved by reducing the current density in the windings (in order to reduce the losses in the copper) and by choosing a thinner steel sheet (in order to reduce the losses in the steel).

As a last step of the present paper the program outputs all necessary data for the transformer production: sort of steel, thickness of the steel sheet, type and shape of the core, type and thickness of the dielectric for making the spool, type and thickness the dielectrics between the windings and between the turns in them, number of the turns in the windings, diameter, type and thermal class of the conductors. The program outputs information about the basic parameters of the designed transformer: coefficient of efficiency, losses of the active materials (in the copper P_M and in the steel P_{St}), coefficient of admission the window K_3, coefficient of weight α, all dimensions of the selected core, etc.

IV. Conclusion

It is well - known the methodology by which the ST construction is optimized [1]. But the existing software does not read a great part of the criteria for optimization (some opportunities for selection offered by the methodology are neglected in the available programs – there are constant data of many parameters). Beside that, the available so far programming products do not give an opportunity to choose the most widely used in our country sorts of steel, enameled conductors, dielectrics, etc. There is an opportunity to select criteria for the optimization and ways to approach it. As such criteria are offered either the requirement for minimization of the mass (volume) and overheating (or high coefficient of efficiency) of the ST or the requirement for minimization of the voltage-drops and its cost. The correlation between the area of the winding and the dimensions of the core window, the frequency of the voltage supply, the type and shape of the core, the sort of the material, etc. are used as ways to approach the optimization.

```
#include<iostream.h>
#include<math.h>
typedef struct MAG1type
{
char tip[13];                 double y1,y2,b,h,Q,l0,Vc;
} t1;
typedef struct MAG2type
{
char tip[10];                 double y1,h,b,y3,y2,Q,Vc,l0;
} t2;
typedef struct MAG3type
{
char tip[8];                  double y1,y2,y3,h,b,Q,l0;
} t3;
typedef struct PETtype
{
 double d,di,r0;
}t4;
int getint()
{
int i;                        char c;                       while (1)
{
cin>>c;                       switch (c)
{
case '0': case '1': case '2': case '3': case '4':
case '5': case '6': case '7': case '8': case '9':
cin.putback(c);               cin>>i;                       return i;
} } }
double getdouble()
{
double i;                     char c;                       while (1)
{
cin>>c;                       switch (c)
{
case '0': case '1': case '2': case '3': case '4':
case '5': case '6': case '7': case '8': case '9': case '.':
cin.putback(c);               cin>>i;             return i;
} } }
double getgr(double tab[6],double P)
{
if (P>200) return tab[4]+(tab[5]-tab[4])*(P-200)/300;
if (P>100) return tab[3]+(tab[4]-tab[3])*(P-100)/100;
if (P>50) return tab[2]+(tab[3]-tab[2])*(P-50)/50;
if (P>20) return tab[1]+(tab[2]-tab[1])*(P-20)/30;
return tab[0]+(tab[1]-tab[0])*P/20;
}
double DU(double tab[5],double P)
{
if (P>300) return tab[3]+(tab[4]-tab[3])*(P-300)/200;
if (P>150) return tab[2]+(tab[3]-tab[2])*(P-150)/150;
if (P>50) return tab[1]+(tab[2]-tab[1])*(P-50)/100;
```

```
return tab[0]+(tab[1]-tab[0])*P/50;
}
double p(double tab[3],double B)
{
if (B>1.5) return tab[1]+(tab[2]-tab[1])*(B-1.5)/0.2;
return tab[0]+(tab[1]-tab[0])*(B-1)/0.5;
}
void main()
{
MAG1type MAG1[32]={{"пл10x12,5-20" ,10 ,12.5 ,12.5 ,20 },
                                        :
                   {"пл40x80-200" ,40 ,80 ,64 ,200 ,28.6 }};
MAG2type MAG2[28]={{"шл10x10"     ,10 ,25 ,10 ,5   ,10   },
                                        :
                   {"шл40x80" ,40 ,100 ,40 ,20 ,80 ,28.4 }};
MAG3type MAG3[38]={{"ш-3x3"   ,3  ,3   ,2  ,10 ,4  ,0.079},
                                        :
                    {"ш-32x64" ,32 ,64  ,16   ,80   ,32 ,18  }};
PETtype PET[69]={{0.06 ,0.085 ,6198},
                                        :
                    {2.44 ,2.54  ,3.75}};
double Bmag12[6]={1.5,1.54,1.58,1.62,1.66,1.7};
double Bmag3[6]={1.36,1.38,1.42,1.46,1.52,1.63};
double deltamin0[6]={3.6,3.6,3.4,3,2.3,2};
double deltamax0[6]={7,5.5,4.3,3.7,3.1,2.7};
double DU1[5]={15,5,4,3,2};
double DU2[5]={20,10,8,6,5};
double KPD0[5]={0.6,0.8,0.9,0.93,0.94};
double p1[3]={1.1,2.45,3.2};
double p2[3]={0.8,1.75,2.5};
double p3[3]={0,1.5,2.2};
double p4[3]={0.8,1.75,2.5};
double p5[3]={0.6,1.3,1.9};
double p6[3]={0,1.2,1.8};
char KLAS='Y';
intST=310,i,j,k,n,MAK,OHL,NAV,WANT,f=1,MAGTYP,PETin[3],PETout[11];
double isol,P2=0,P,nisol=0.22,Umax=0,KI,c,lent,alfa=2.5,alfamax=
      3.5,DMAK=5,B,delta,deltamin;
double Q,EW,Wmin,Wcor,h,b,y1,y2,y3,BB,HH,l0,Vst,KZ,Gst,Gm,Pst,Pm,KPD;
double Uin[3],Iin[3],Win[3],Din[3],WinP[3],Cin[3],Ain[3];
double Uout[11],Iout[11],Wout[11],Dout[11],WoutP[11],Aout[11];
while (k<1||k>2)
{
cout<<endl<<"Брой първични намотки - k (1..2):";
k=getint();
}
cout<<"                    k="<<k;
cout<<endl<<"Входни напрежения (110..380V):";
for (i=1;i<=k;i++)
{
while (Uin[i]<110||Uin[i]>380)
{
cout<<endl<<"Uin"<<i<<"=";              Uin[i]=getdouble();
}
cout<<"              Uin"<<i<<"="<<Uin[i]<<"V";
}
while (n<1||n>10)
{
cout<<endl<<"Брой вторични намодки - n (1..10):";
n=getint();
}
cout<<"                    n="<<n;
cout<<endl<<"Изходни напрежения (1..1000V):";
for (i=1;i<=n;i++)
{
while (Uout[i]<1||Uout[i]>1000)
{
cout<<endl<<"Uout"<<i<<"=";
Uout[i]=getdouble();
}
cout<<"           Uout"<<i<<"="<<Uout[i]<<"V";
}
cout<<endl<<"Изходни токове (0.001..10A):";       for (i=1;i<=n;i++)
{
while (Iout[i]<0.001||Iout[i]>10)
{
cout<<endl<<"Iout"<<i<<"=";             Iout[i]=getdouble();
}
cout<<"            Iout"<<i<<"="<<Iout[i]<<"A";
}
while (!(isol==0.05||isol==0.06||isol==0.07||isol==0.08))
{
cout<<endl<<"изолация между навив.-isol (0.05/0.06/0.07/0.08):";
isol=getdouble();
}
cout<<"        isol="<<isol;  while (MAK<1||MAK>3)
{
cout<<endl<<"М-ал за макара (1=пресшпан/2=гетинакс/3=текстолит):";
MAK=getint();
}
cout<<"            Макара от ";         switch (MAK)
{
case 1:cout<<"пресшпан";break;
case 2:cout<<"гетинакс";break;
case 3:cout<<"текстолит";
}
while (OHL<1||OHL>3)
{
cout<<endl<<"Охлаждане (1=с вентилатор/2=с естествени отвори/3=без
отвори):";                    OHL=getint();
}
cout<<"            Охлаждане ";                   switch (OHL)
{
case 1:cout<<"с вентилатор";tita0=26;break;
case 2:cout<<"с естествени отвори";tita0=30;break;
case 3:cout<<"без отвори";tita0=35;
}
while (NAV<1||NAV>2)
{
cout<<endl<<"Навиване (1=ръчно/2=машинно):";
NAV=getint();
}
switch (NAV)
{
case 1:cout<<"                          Ръчно";KI=1.4;break;
case 2:cout<<"                          Машинно";KI=1.3;
}
cout<<" навиване";                          while (WANT<1||WANT>2)
{
cout<<endl<<"Изискване (1=за мин. цена/2=за мин. тегло):";
WANT=getint();
}
cout<<"            Изискване за минималн";         switch (WANT)
{
case 1:cout<<"а цена";break;  case 2:cout<<"о тегло";
}
cout<<endl<<endl<<endl<<endl;
for (i=1;i<=n;i++)P2+=Uout[i]*Iout[i];   P=1.039*P2;  if (P>500)
{
cout<<"голяма мощност P>500W (P="<<P<<")!"<<endl; return;
}
for (i=1;i<=k;i++) Iin[i]=1.077*(P2/Uin[i]);                if (k==2)
{
if (Uin[2]>Uin[1]) Uin[2]-=Uin[1];                          else
{
f=2;                                                 Uin[1]-=Uin[2];
} }
for (i=1;i<=k;i++) if (Uin[i]>Umax) Umax=Uin[i];
for (i=1;i<=n;i++) if (Uout[i]>Umax) Umax=Uout[i];
if (Umax<400)
{
nisol=0.11;                   if (Umax<220) nisol=0.09;
}
if (P<200)
{
c=0.7;                        if (WANT==1)
{
MAG=3;                        lent=0.5;
}
else
{
MAG=2;                        lent=0.35;
}  }
else
{
c=0.6;                        MAG=1;              lent=0.35;
}
if (WANT==1)
{
alfa=4.5;                                         alfamax=5.5;
}
if (P<=400) DMAK=4;      if (P<=300) DMAK=3;         if (P<=200)
{
DMAK=2;                                 if (MAK==1) DMAK=2.5;
}
if (P<=150)
{
DMAK=1.5;                               if (MAK==1) DMAK=2;
}
if (P<=100)
{
DMAK=1.5;                               if (MAK==2) DMAK=1.2;
}
if (P<=50)
{
DMAK=0.8;                               if (MAK==1) DMAK=1;
}
if (P>200&&MAK==1) DMAK=2;        if (MAG==3) B=getgr(Bmag3,P);
else B=getgr(Bmag12,P);           deltamin=getgr(deltamin0,P);
delta=getgr(deltamax0,P);
Qcalc:
Q=10*c*sqrt((P*alfa)/(50*B*delta));               switch (MAG)
{
case 1:for (i=31;i>=0;i--) if (Q<MAG1[i].Q) MAGTYP=i;break;
case 2:for (i=27;i>=0;i--) if (Q<MAG2[i].Q) MAGTYP=i;break;
case 3:for (i=37;i>=0;i--) if (Q<MAG3[i].Q) MAGTYP=i;
}
MAGset:
switch (MAG)
{
case 1:
Q=MAG1[MAGTYP].Q;     l0=MAG1[MAGTYP].l0;     y1=MAG1[MAGTYP].y1;
y2=MAG1[MAGTYP].y2;  h=MAG1[MAGTYP].h;      b=MAG1[MAGTYP].b;
BB=2*y1+b;    HH=2*y1+h;      Vst=MAG1[MAGTYP].Vc;         break;
case 2:
Q=MAG2[MAGTYP].Q;    l0=MAG2[MAGTYP].l0;    y1=MAG2[MAGTYP].y1;
y2=MAG2[MAGTYP].y2;  y3=MAG2[MAGTYP].y3;    h=MAG2[MAGTYP].h;
b=MAG2[MAGTYP].b;    BB=2*y3+y1+b;          HH=2*y3+h;
Vst=MAG2[MAGTYP].Vc;        break;
case 3:
Q=MAG3[MAGTYP].Q;    l0=MAG3[MAGTYP].l0;     y1=MAG3[MAGTYP].y1;
y2=MAG3[MAGTYP].y2;  y3=MAG3[MAGTYP].y3;     h=MAG3[MAGTYP].h;
b=MAG3[MAGTYP].b;    BB=2*y3+y1+b;           HH=2*y3+h;
Vst=(HH*BB-2*b*h)*y2;
}
EW=0.0222*B*Q;
for(i=1;i<=k;i++) Win[i]=Uin[i]*(1-DU(DU1,P)/100)/EW;
for(i=1;i<=n;i++) Wout[i]=Uout[i]*(1+DU(DU2,P)/100)/EW;
Wmin=Win[1];
for (i=1;i<=k;i++) if (Win[i]<Wmin) Wmin=Win[i];
for (i=1;i<=n;i++) if (Wout[i]<Wmin) Wmin=Wout[i];
Wcor=int(Wmin+0.5)/Wmin;
for (i=1;i<=k;i++) Win[i]=int(Win[i]*Wcor+0.5);
for (i=1;i<=n;i++) Wout[i]=int(Wout[i]*Wcor+0.5);
for (i=1;i<=n;i++) Dout[i]=1.130*sqrt(Iout[i]/delta);
for (i=1;i<=k;i++) for (j=68;j>=0;j--) if (Din[i]<PET[j].d)
PETin[i]=j;
for (i=1;i<=n;i++) for (j=68;j>=0;j--) if (Dout[i]<PET[j].d)
PETout[i]=j;
for (i=1;i<=k;i++) WinP[i]=int((h-2*DMAK)/PET[PETin[i]].di);
for (i=1;i<=n;i++) WoutP[i]=int((h-2*DMAK)/PET[PETout[i]].di);
for (i=1;i<=n;i++) Cout[i]=1+int(Wout[i]/WoutP[i]);
for (i=1;i<=k;i++) Ain[i]=nisol+(Cin[i]*Din[i]+(Cin[i]-1)*isol)*KI;
```

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