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(54) **Title**: A SYSTEM AND METHOD FOR DESIGN ANALYSIS FOR METAL CASTING DESIGN

(57) **Abstract**: A system for design analysis for metal casting design of a part to be cast, said system comprises: input mechanism to receive an input file relating to said part; undercut identification mechanism adapted to identify undercut region(s) in the design of the input file; parting line location mechanism adapted to identify parting line location based on identified undercut region(s) and to identify parting line direction; orientation defining mechanism adapted to define orientation of part to be placed for casting; hot spots' identification mechanism adapted to identify hotspots that may be possible in the designed geometry of the input file; feeder modulus computation mechanism adapted to compute feeder dimensions for the part that is to be cast based on identified hotspots; feeder positioning mechanism adapted to determine feeder position in relation to pre-determined parameters; and directional solidification analysis mechanism adapted to problem areas related to directional solidification, shrinkage porosity during casting solidification.

A SYSTEM AND METHOD FOR DESIGN ANALYSIS FOR METAL CASTING DESIGN

Field of the Invention:

This invention relates to the field of computational systems and simulation systems.

Particularly, this invention relates to metal casting and designing systems.

Specifically, this invention relates to a system and method for design analysis for metal casting design.

Background of the Invention:

Casting, one of the oldest manufacturing processes, dates back to 4000 B.C. when copper arrowheads were made.

Casting is a manufacturing process by which a liquid material is usually poured into a mold, which contains a hollow cavity of the desired shape, and is then allowed to solidify. The solidified part is also known as a casting, which is ejected or broken out of the mold to complete the process. Casting materials are usually metals. Casting is most often used for making complex shapes that would be otherwise difficult or uneconomical to make by other methods.

Metal casting is one of the most common casting processes.

A casting defect is an irregularity in the metal casting process that is undesired. Some defects can be tolerated while others can be repaired; otherwise, they must be eliminated. They are broken down into five main categories: gas porosity, shrinkage defects, mold material defects, pouring metal defects, and metallurgical defects.

Part design, by its very nature, is iterative. For a product to take shape, there are multiple sets of players: 1) Product designers; 2) Tooling shop or pattern workshop; and 3) Foundry workshop. Typically, a product designer aesthetically and functionally designs a product and then expects the tooling shop or the foundry workshop to manufacture the same. This leads to problems such as ad hoc changes to the part design, weight differences as compared to designed part, changes to part design that spoil aesthetics, increase in wall thickness in some areas, unwarranted changes in part weight, and the like which impact competitiveness of the part design. However, a functionally and aesthetically designed part by a product designer may not be easily castable. A good casting design needs to satisfy several criteria: identify the right kind of alloy and casting process, design an economical mold, ensure that the design reduces tendency to create hot spots in critical regions, ensure that the part design supports a robust rigging system which promotes directional solidification, and ensure that secondary processes reduce dimensional variation. A product designer requires tools and apparatus that assist him in designing products for castability thereby ensuring lower costs and better turnaround quality and time.

Casting process simulation uses multiple techniques including numerical methods to calculate cast component quality considering mold filling, solidification and cooling, and provides a quantitative prediction of casting mechanical properties, thermal stresses and distortion. Simulation accurately describes a cast component's quality up-front before production starts. The casting rigging can be designed with respect to the required component quality and properties. This has benefits beyond a reduction in pre-production sampling, as the precise layout of the complete casting system also leads to energy, material, and tooling savings.

The simulation supports the user in component design, the determination of melting practice and casting method through to pattern and mold making, heat treatment, and finishing. This saves costs along the entire casting manufacturing route.

The feeding mechanism during casting solidification can be directly visualized by computing and plotting the path along which molten feed metal moves to compensate volumetric contraction. The soundness of a cast part depends on an uninterrupted flow of molten feed metal along feed-paths.

According to an exemplary embodiment, one of the many challenges for a product and tooling engineer is where and how to place riser bosses in sand casting process. A lot of time is spent in discussing with foundry to finalize Riser location and size, taper angle to be provided to these bosses, and where should 'Parting Line' be placed. Moreover, these risers are undesirable for a product designer which implies the location and size of risers is important.

In conventional approaches, a lot of time and trials are wasted in solving these questions through iterations of actual casting and designing and redesigning the actual profile modeled by designer and the one achieved on castings. Additionally, sometimes tooling designer, foundry adds material to products to smoothen out surface profiles (e.g. in case of undercuts, sharp corners). They want to ensure less expensive moldability and smooth material flow during pouring. There is a need to provide a simulated system and method which reduces the time for casting development by providing a design with actual feedback from multiple perspectives in relation to true-world rules of casting.

Objects of the Invention:

An object of the invention is to provide a system and method which provides a simulation based design analysis tool for cost effective casting designs.

Another object of the invention is to provide a system and method which aids in casting design simulation, which system and method is meant for product and tooling designers.

Yet another object of the invention is to provide a system and method which aids in casting design simulation, which system and method is integrated with a CAD system.

Still another object of the invention is to provide a system and method which aids in casting design simulation, which system and method is meant to ensure cost effective metal casting design.

An additional object of the invention is to provide a system and method which aids in casting design simulation, which system and method is a combination of a simulation based and rule based approach.

Summary of the Invention:

According to this invention, there is provided a system for design analysis for metal casting design of a part to be cast, said system comprises:

i. input mechanism adapted to receive at least an input file relating to said part, said input file being a set of triangles which represent said part;
ii. undercut identification mechanism adapted to identify undercut region(s) in the design of the input file;
iii. parting line location mechanism adapted to identify parting line location based on identified undercut region(s) and to identify parting line direction;
iv. orientation defining mechanism adapted to define orientation of part (corresponding to the mold/casting assembly) to be placed for casting;
v. hot spots' identification mechanism adapted to identify hotspots that may be possible in the designed geometry of the input file;

vi. feeder modulus computation mechanism adapted to compute feeder dimensions for the part that is to be cast based on identified hotspots;
vii. feeder positioning mechanism adapted to determine feeder position in relation to pre-determined parameters; and
viii. directional solidification analysis mechanism adapted to problem areas related to directional solidification, shrinkage porosity during casting solidification.

In at least one embodiment, said undercut identification mechanism comprises a voxelization mechanism configured to voxelize mold box and further comprises a first computation mechanism configured to compute a list of triangles intersecting with each voxel, characterised in that, a direction mechanism being configured to choose a direction and then computing a first associated voxel in said chosen direction, said association being in respect to at least a computed triangle further wherein for all the triangles associated with these voxels, if normal is directed opposite to the view direction, triangle is visible and all triangles which do not satisfy the above criteria, are obscured by default, thereby forming identified potential undercut region(s) from said visible triangles.

In at least one embodiment, said parting line location mechanism comprises:
i. first determination mechanism configured to determine whether all surface voxels are linked to identified region(s);
ii. second determination mechanism configured to determine if surface undercut voxels are combined into well-connected areas;
iii. third determination mechanism configured to determine if each identified undercut region is an internal undercut region or an external undercut region, wherein a triangle is considered to be part of an internal undercut region if said triangle is obscure in both positive and negative directions of at least one orientation of said part;
iv. second computation mechanism configured to compute undercut volume and undercut area for all possible external undercuts along major axes; and
v. fourth determination mechanism in order to determine part orientation based on computed undercut volume and computed undercut area, characterised in that, a drag part of said mold being a relatively heavier part and a cope part of said mold being a relatively lighter part.

In at least one embodiment, said parting line location mechanism comprises:
i. minimum undercut parting direction mechanism configured to define minimum undercut parting direction;

ii. visibility computation mechanism configured to compute visibility in all pre-defined directions;
iii. area computation mechanism configured to compute area(s) of undercuts in each orientation; and
iv. third computation mechanism configured to compute and select minimum draw as parting direction if more than one orientation has minimum undercut area.

In at least one embodiment, said parting line location mechanism comprises:

i. maximum silhouette parting line mechanism configured to provide a location of a parting line based on largest / maximum silhouette;
ii. fifth determination mechanism configured to determine a parting direction;
iii. transformation mechanism configured to transform co-ordinates of said mold design based on determined parting direction such that Z-axis is oriented towards the corresponding chosen direction, and X-axis and Y-axis is oriented towards remaining two directions;
iv. maximum value computation mechanism configured to compute maximum X and Y values and corresponding Z co-ordinates;
v. minimum value computation mechanism configured to compute minimum X and Y values and corresponding Z co-ordinates;
vi. sectioning mechanism configured to section the part at each of these Z-locations to form sectioned plane(s);
vii. part edges' and vertices' computation mechanism configured to compute part edges and vertices at said sectioned plane;
viii. 2D bounding box computation mechanism configured to compute a 2D bounding box of each sectioned plane(s) using maximum and minimum X and Y values which are computed from these vertices;
ix. comparator mechanism configured to compare and choose a sectioned plane with maximum 2D bounding box area as parting line;
characterised in that, when there are multiple sectioned plane(s) in said 2D bounding box, said system further comprise:
selection mechanism configured to choose sectioned plane(s) when multiple sectioned planes have maximum 2D bounding box areas, said selection mechanism being governed by pre-defined rules, said pre-defined rules comprise the steps of a) selecting sectioned plane(s) having planar faces normal to parting direction, b) selecting planar faces over cylindrical, c) selecting cylindrical faces with larger radii over those with smaller radii, selecting section closer to centroid of a given geometry if multiple sectioned planar faces exist;

x. loop formation mechanism configured to form closed loops from all the edges of said chosen 2D bounding box; and
xi. parting line formation mechanism configured to form and display said loops of silhouette edges as parting line.

In at least one embodiment, said parting line location mechanism comprises:
i. part symmetricity computation mechanism configured to compute part symmetricity in all directions;
ii. fifth determination mechanism configured to determine a parting direction;
iii. transformation mechanism configured to transform co-ordinates of said mold design based on determined parting direction such that Z-axis is oriented towards the corresponding chosen direction, and X-axis and Y-axis is oriented towards remaining two directions;
iv. maximum value computation mechanism configured to compute maximum X and Y values and corresponding Z co-ordinates;
v. minimum value computation mechanism configured to compute minimum X and Y values and corresponding Z co-ordinates;
vi. sectioning mechanism configured to section the part at each of these Z-locations to form sectioned plane(s);
vii. part edges' and vertices' computation mechanism configured to compute part edges and vertices at said sectioned plane;
viii. 2D bounding box computation mechanism configured to compute a 2D bounding box of each section plane(s) using maximum and minimum X and Y values which are computed from these vertices;
ix. symmetricity comparator mechanism configured to compare symmetricity of the part in more than one direction and if the part is symmetric in more than one direction, the direction with minimum draw is chosen as parting direction otherwise the direction with minimum external undercuts is chosen as parting direction; and
x. sixth computation mechanism configured to compute and select minimum draw based on 2D bounding box computation for each of the axes of symmetricity.

In at least one embodiment, said parting line location mechanism comprises mechanisms to locate parting line based on feed path to an identified hotspot.

In at least one embodiment, said parting line location mechanism comprises:
i. minimum draw parting direction mechanism configured to define minimum draw parting direction;

ii. transformation mechanism configured to transform co-ordinates of said mold design based on determined parting direction such that Z-axis is oriented towards the corresponding chosen direction, and X-axis and Y-axis is oriented towards remaining two directions;
iii. maximum value computation mechanism configured to compute maximum Z values;
iv. minimum value computation mechanism configured to compute minimum maximum Z values; and
v. selection mechanism configured to select a direction with maximum value selected from computed minimum Z values and maximum Z values which is chosen as parting direction.

In at least one embodiment, said orientation defining mechanism comprises:
i. part orientation mechanism configured to determine a part orientation;
ii. transformation mechanism configured to transform co-ordinates of said mold design based on determined parting direction such that Z-axis is oriented towards the corresponding chosen direction, and X-axis and Y-axis is oriented towards remaining two directions;
iii. maximum value computation mechanism configured to compute maximum X and Y values and corresponding Z co-ordinates;
iv. minimum value computation mechanism configured to compute minimum X and Y values and corresponding Z co-ordinates;
v. line drawing mechanism configured to draw at least a parting line wherein corresponding vertices are taken as extreme points from parting line;
vi. vertices' distance computation mechanism configured to compute distance between these two vertices (maximum Z and minimum Z) from a parting line; and
vii. drag side determination mechanism comprising a comparator to determine a side with a relatively larger distance in order to determine it as drag side; and
viii. cope side determination mechanism comprising a comparator to determine a side with a relatively smaller distance in order to determine it as cope side.

In at least one embodiment, said orientation defining mechanism comprises:
i. part orientation mechanism configured to determine a part orientation;
ii. transformation mechanism configured to transform co-ordinates of said mold design based on determined parting direction such that Z-axis is oriented towards the corresponding chosen direction, and X-axis and Y-axis is oriented towards remaining two directions;

iii. maximum value computation mechanism configured to compute maximum X and Y values and corresponding Z co-ordinates;
iv. minimum value computation mechanism configured to compute minimum X and Y values and corresponding Z co-ordinates;
v. line drawing mechanism configured to draw at least a parting line wherein corresponding vertices are taken as extreme points from parting line;
vi. splitting mechanism configured to split the part and compare weight of the part above and below the parting line;
vii. weight comparator mechanism configured to compare and determine a side with a relatively higher weight in order to determine it as drag side; and
viii. weight comparator mechanism configured to compare and determine a side with a relatively lower weight distance in order to determine it as cope side.

In at least one embodiment, said orientation defining mechanism comprises:
i. part orientation mechanism configured to determine a part orientation;
ii. transformation mechanism configured to transform co-ordinates of said mold design based on determined parting direction such that Z-axis is oriented towards the corresponding chosen direction, and X-axis and Y-axis is oriented towards remaining two directions;
iii. maximum value computation mechanism configured to compute maximum X and Y values and corresponding Z co-ordinates;
iv. minimum value computation mechanism configured to compute minimum X and Y values and corresponding Z co-ordinates;
v. line drawing mechanism configured to draw at least a parting line wherein corresponding vertices are taken as extreme points from parting line;
vi. comparator mechanism configured to compare and determine a side with a relatively lower concentration of hotspots in order to determine it as drag side; and
vii. comparator mechanism configured to compare and determine a side with a relatively higher concentration of hotspots in order to determine it as cope side.

In at least one embodiment, said system comprises:
i. temperature computation mechanism configured to compute temperature of part voxels using Gradient Vector Method;
ii. temperature normalization mechanism configured to normalize temperature of all part voxels with respect to the maximum temperature among said part voxels, with maximum normalized temperature being 1 and minimum normalized temperature being 0; and

iii. hotspot temperature cutoff definition mechanism configured to define hotspot temperature cutoff as the ratio of materials solidus temperature to material liquidus temperature;

iv. a processing mechanism configured to perform the following steps:

a) marking all voxels with normalized temperature greater than hotspot temperature cutoff as possible hotspot voxels;
b) combining hotspot voxels and identifying a hotspot by means of a pre-defined hotspot attribute;
c) identifying a hotspot by means of a pre-defined hotspot attribute;
d) determining volume of all hotspots;
e) defining volume as number of voxels marked with said pre-defined hotspot attribute;
f) computing area for each surface voxel by performing a first step proceeding in the direction of temperature gradient till a hotspot voxel is reached, and further performing a second step of increasing area count by a factor if the hotspot is the one for which modulus is being computed, wherein area is computed by multiplying area count by surface area of each voxel;
g) computing volume by multiplying number of voxels having hotspot attribute with volume of voxel;
h) computing modulus as a ratio of computed volume to computed surface area;
i) computing feeder modulus as a factor of computed modulus, thereby determining feeder dimensions, accordingly, said factor being selected based on material and process being used; and
j) computing neck modulus as a factor of computed modulus, said factor being selected based on material and process being used.

In at least one embodiment, said feeder positioning mechanism comprises a processing mechanism configured to perform the following steps in order to determine feeder position:

i. evaluating a hot spot region in order to identify the centroid and hottest temperature;
ii. determining feed path in order to effectively feed the hotspot;
iii. determining directional solidification in order to have defect free castings.

In at least one embodiment, said feeder positioning mechanism comprises a processing mechanism configured to perform the following steps in order to determine feeder position:

i. determining fettleability in order to place the feeder properly;

ii. determining intersection checks in order to ensure feeder is not too close to the original part surface; and
iii. evaluating and analysing flat areas for fettling relating issues.

In at least one embodiment, said feeder positioning mechanism comprises a processing mechanism configured to determine position of feeder based on following rules:
i. giving planar faces first priority;
ii. giving cylindrical faces second priority;
iii. for each location, ensuring that part thickness is more than feeder thickness by a pre-determined factor;
iv. for hot spots closer to top of part, preferring top feeders;
v. for hot spots closer to parting line, preferring side feeders.

In at least one embodiment, said system further comprises a feeder geometry computation mechanism configured to compute feeder geometry based on pre-defined parameters relating to casting, relating to designed part, and relating to identified parameters of the mold and casting, said feeder geometry computation mechanism comprise:
i. determination mechanism configured to determine feeder dimension(s) based on hotspot modulus;
ii. determination mechanism configured to determine feeder dimension(s) based on hotspot modulus, characterised in that, said neck modulus is a pre-determined factor of hotspot modulus;
iii. determination mechanism configured to determine feeder dimension(s) based on hotspot modulus, said feeder modulus is a pre-determined factor of hotspot modulus;
iv. determination mechanism configured to determine feeder dimension(s) based on hotspot modulus, said modulus of feeder being determined as a function of modulus of casting region and feeder design factor based on material

In at least one embodiment, said directional solidification analysis mechanism comprises a processing mechanism configured to perform the following steps:
i. for each part hotspot, section being taken with feeder;
ii. a unique path being identified for joining part hotspot and feeder hotspot;
iii. temperature along the path joining hotspot and feeder being analyzed to look at any undesired pattern based on rules that are defined based on material, process, geometry inter-relationships; and
iv. iterating changes in design if required.

In at least one embodiment, said directional solidification analysis mechanism comprises a processing mechanism configured to perform the following steps, for each hotspot:

i. determining that if volume of the hotspot in part is zero, then direction solidification is occurring;
ii. associating nearest feeder hotspot as feeder hotspot;
iii. estimating a shortest path joining core of part hotspot and core of feeder hotspot along a skeleton, said skeleton being computed using Palagyi's technique by defining the nearest voxel on skeleton as end points and using computationally efficient technique to find the shortest path; and
iv. determining that if along the path, if at any voxel, the difference between voxel temperature and end point temperature is more than a predefined temperature then considering the hotspot as not being fed and therefore determining that directional solidification is not occurring.

According to this invention, there is also provided a method for design analysis for metal casting design of a part to be cast, said method comprises the steps of:

i. receiving at least an input file relating to said part, said input file being a set of triangles which represent said part;
ii. identifying undercut region(s) in the design of the input file;
iii. identifying parting line location based on identified undercut region(s)and to identify parting line direction;
iv. defining orientation of object (corresponding to the mold/casting assembly) to be placed for casting;
v. identifying hotspots that may be possible in the designed geometry of the input file;
vi. computing feeder dimensions for the object that is to be cast based on identified hotspots;
vii. determining feeder position in relation to pre-determined parameters; and
viii. indicating problem areas related to directional solidification, shrinkage porosity during casting solidification.

In at least one embodiment, said identifying undercut region(s) in the design of the input file further comprises a step of voxelizing mold box and further comprise a step of computing a list of triangles intersecting with each voxel, characterised in that, said method being characterised by providing a further step of choosing a direction and then computing a first associated voxel in said chosen direction, said association being in respect to at least a computed triangle further wherein for all the triangles associated with these voxels, if normal is directed opposite to the view direction, triangle is visible and all triangles which do not satisfy the above criteria, are obscured by default, thereby forming identified potential undercut region(s)from said visible triangles.

In at least one embodiment, said step of identifying parting line location further comprises the steps of:

i. determining whether all surface voxels are linked to identified region(s);
ii. determining if surface undercut voxels are combined into well-connected areas;
iii. determining if each identified undercut region is an internal undercut region or an external undercut region, wherein a triangle is considered to be part of an internal undercut region if said triangle is obscure in both positive and negative directions of at least one orientation of said part;
iv. computing undercut volume and undercut area for all possible external undercuts along major axes; and
v. determining part orientation based on computed undercut volume and computed undercut area, characterised in that, a drag part of said mold being a relatively heavier part and a cope part of said mold being a relatively lighter part.

In at least one embodiment, said step of identifying parting line location further comprises the steps of:

i. defining minimum undercut parting direction;
ii. computing visibility in all pre-defined directions;
iii. computing area(s) of undercuts in each orientation; and
iv. computing and selecting minimum draw as parting direction if more than one parting direction has minimum undercut area.

In at least one embodiment, said step of identifying parting line location further comprises the steps of:

i. providing a location of a parting line based on largest / maximum silhouette;
ii. determining a parting direction;
iii. transforming co-ordinates of said mold design based on determined parting direction such that Z-axis is oriented towards the corresponding chosen direction, and computing maximum and minimum X and Y values and corresponding Z values;
iv. sectioning the part at each of these Z-locations to form sectioned plane(s), and computing part edges and vertices at said sectioned plane;

v. computing a 2D bounding box of each sectioned plane(s) using maximum and minimum X and Y values which are computed from these vertices;

vi. comparing and choosing a sectioned plane with maximum 2D bounding box area as parting line;

characterised in that, when there are multiple sectioned plane(s) in said 2D bounding box, said method further comprise the steps of:

choosing sectioned plane(s) when multiple sectioned planes have maximum 2D bounding box areas, said selection mechanism being governed by pre-defined rules, said pre-defined rules comprise the steps of a) selecting sectioned plane(s) having planar faces normal to parting direction, b) selecting planar faces over cylindrical, c) selecting cylindrical faces with larger radii over those with smaller radii, selecting section closer to centroid of a given geometry if multiple sectioned planar faces exist;

vii. forming closed loops from all the edges of said chosen 2D bounding box; and

viii. forming and displaying said loops of silhouette edges as parting line.

In at least one embodiment, said step of identifying parting line location further comprises the steps of:

i. computing part symmetricity in all directions;
ii. determining a parting direction;
iii. transforming co-ordinates of said mold design based on determined parting direction such that Z-axis is oriented towards the corresponding chosen direction, and computing maximum and minimum X and Y values and corresponding Z values;
iv. sectioning the part at each of these Z-locations to form sectioned plane(s);
v. computing part edges and vertices at said sectioned plane;
vi. computing 2D bounding box of each section plane(s) using maximum and minimum X and Y values which are computed from these vertices;
vii. comparing symmetricity of the part in more than one direction and if the part is symmetric in more than one direction, the direction with minimum draw is chosen as parting direction otherwise the direction with minimum external undercuts is chosen as parting direction; and
viii. computing and selecting minimum draw based on 2D bounding box computation for each of the axes of symmetricity.

In at least one embodiment, said step of identifying parting line location further comprises a step of locating parting line based on feed path to an identified hotspot.

In at least one embodiment, said step of identifying parting line location further comprises the steps of:

i. defining minimum draw parting direction;
ii. transforming co-ordinates of said mold design based on determined parting direction such that Z-axis is oriented towards the corresponding chosen direction, and X-axis and Y-axis is oriented towards remaining two directions;
iii. computing maximum Z values;
iv. computing minimum Z values; and
v. selecting a direction with maximum value selected from computed minimum Z values and maximum Z values which is chosen as parting direction.

In at least one embodiment, said defining orientation of part (corresponding to the mold/casting assembly) to be placed for casting comprises the steps of:

i. determining a part orientation;
ii. transforming co-ordinates of said mold design based on determined parting direction such that Z-axis is oriented towards the corresponding chosen direction, and X-axis and Y-axis is oriented towards remaining two directions;
iii. computing maximum X and Y values and corresponding Z co-ordinates;
iv. computing minimum X and Y values and corresponding Z co-ordinates;
v. drawing at least a parting line wherein corresponding vertices are taken as extreme points from parting line;
vi. computing distance between these two vertices (maximum Z and minimum Z) from a parting line; and
vii. comparing to determine a side with a relatively larger distance in order to determine it as drag side; and
viii. comparing to determine a side with a relatively smaller distance in order to determine it as cope side.

In at least one embodiment, said defining orientation of part (corresponding to the mold/casting assembly) to be placed for casting comprises the steps of:

i. determining a part orientation;
ii. transforming co-ordinates of said mold design based on determined parting direction such that Z-axis is oriented towards the corresponding chosen direction, and X-axis and Y-axis is oriented towards remaining two directions;
iii. computing maximum X and Y values and corresponding Z co-ordinates;
iv. computing minimum X and Y values and corresponding Z co-ordinates;

v. drawing at least a parting line wherein corresponding vertices are taken as extreme points from parting line;
vi. splitting the part and comparing weight of the part above and below the parting line is compared;
vii. comparing to determine a side with a relatively higher weight in order to determine it as drag side; and
viii. comparing to determine a side with a relatively lower weight distance in order to determine it as cope side.

In at least one embodiment, said defining orientation of part (corresponding to the mold/casting assembly) to be placed for casting comprises the steps of:

i. determining a part orientation;
ii. transforming co-ordinates of said mold design based on determined parting direction such that Z-axis is oriented towards the corresponding chosen direction, and X-axis and Y-axis is oriented towards remaining two directions;
iii. computing maximum X and Y values and corresponding Z co-ordinates;
iv. computing minimum X and Y values and corresponding Z co-ordinates;
v. drawing at least a parting line wherein corresponding vertices are taken as extreme points from parting line;
vi. comparing to determine a side with a relatively lower concentration of hotspots in order to determine it as drag side; and
vii. comparing to determine a side with a relatively higher concentration of hotspots in order to determine it as cope side.

In at least one embodiment, said method comprises the steps of:

i. computing temperature of part voxels using Gradient Vector Method;
ii. normalizing temperature of all part voxels with respect to the maximum temperature among said part voxels, with maximum normalized temperature being 1 and minimum normalized temperature being 0;
iii. defining hotspot temperature cutoff as the ratio of materials solidus temperature to material liquidus temperature;
iv. marking all voxels with normalized temperature greater than hotspot temperature cutoff as possible hotspot voxels;
v. combining hotspot voxels and identifying a hotspot by means of a pre-defined hotspot attribute;
vi. computing area for each surface voxel by performing a first step proceeding in the direction of temperature gradient till a hotspot voxel is reached, and further performing a second step of increasing area count by a factor if the

hotspot is the one for which modulus is being computed, wherein area is computed by multiplying area count by surface area of each voxel;

vii. computing volume by multiplying number of voxels having hotspot attribute with volume of voxel;

viii. computing modulus as a ratio of computed volume to computed surface area;

ix. computing feeder modulus as a factor of computed modulus, thereby determining feeder dimensions, accordingly, said factor being selected based on material and process being used; and

x. computing neck modulus as a factor of computed modulus, said factor being selected based on material and process being used.

In at least one embodiment, said step of determining feeder position in relation to pre-determined parameters further comprises the following steps in order to determine feeder position:

i. evaluating a hot spot region in order to identify the centroid and hottest temperature;

ii. determining feed path in order to effectively feed the hotspot; and

iii. determining directional solidification in order to have defect free castings.

In at least one embodiment, said step of determining feeder position in relation to pre-determined parameters further comprises the following steps in order to determine feeder position:

i. determining fettleability in order to place the feeder properly;

ii. determining intersection checks in order to ensure feeder is not too close to the original part surface; and

iii. evaluating and analysing flat areas for fettling relating issues.

In at least one embodiment, said step of determining feeder position in relation to pre-determined parameters being based on following rules:

i. giving planar faces first priority;

ii. giving cylindrical faces second priority;

iii. for each location, ensuring that part thickness is more than feeder thickness by a pre-determined factor;

iv. for hot spots closer to top of part, preferring top feeders; and

v. for hot spots closer to parting line, preferring side feeders are preferred.

In at least one embodiment, said method further comprises a step of computing feeder geometry based on pre-defined parameters relating to casting, relating to designed part, and relating to identified parameters of the mold and casting, further wherein:

i. said step of determining feeder dimension(s) is based on hotspot modulus;
ii. said step of determining feeder dimension(s) comprise a step of determining feeder dimension(s) is based on hotspot modulus, characterised in that, said neck modulus is a pre-determined factor of hotspot modulus;
iii. said step of determining feeder dimension(s) is based on hotspot modulus, characterised in that, said feeder modulus is a pre-determined factor of hotspot modulus;
iv. said step of computing feeder dimensions for the part that is to be cast is based on identified hotspots, characterised in that, said modulus of feeder being determined as a function of modulus of casting region and feeder design factor based on material

In at least one embodiment, said step of indicating problem areas during casting further comprises the following steps:

i. for each part hotspot, section being taken with feeder;
ii. a unique path being identified for joining part hotspot and feeder hotspot;
iii. temperature along the path joining hotspot and feeder being analyzed to look at any undesired pattern based on rules that are defined based on material, process, geometry inter-relationships; and
iv. iterating changes in design if required.

In at least one embodiment, said step of indicating problem areas during casting further comprises the following steps, for each hotspot:

i. determining that if volume of the hotspot in part is zero, then direction solidification is occurring;
ii. associating nearest feeder hotspot as feeder hotspot;
iii. estimating a shortest path joining core of part hotspot and core of feeder hotspot along a skeleton, said skeleton being computed using Palagyi's technique by defining the nearest voxel on skeleton as end points and using computationally efficient technique to find the shortest path; and
iv. determining that if along the path, if at any voxel, the difference between voxel temperature and end point temperature is more than a predefined temperature then considering the hotspot as not being fed and therefore determining that directional solidification is not occurring.

Brief Description of the Accompanying Drawings:

The invention will now be described in relation to the accompanying drawings in which:

Figure 1 illustrates a schematic block diagram of the system;

Figures 2, 3, 4, and 5 illustrate various steps of parting line analysis;

Figures 7, 8, and 9 illustrate the three different parting lines or parting planes that can be seen for a given geometry;

Figure 10 illustrates hotspots at highest threshold of hotspot; and

Figure 11 illustrates feed path direction at a hotspot 1 of the part of Figure 10.

Detailed Description of the Accompanying Drawings:

For the purposes of this specification, the term, '**Hot Spot**' refers to a region within a metal casting which is the last region to solidify. This region is prone to shrinkage porosity defect.

For the purposes of this specification, the term, '**Directional Solidification**' refers to casting process design rules which state that solidification of molten metal should occur in such a manner that liquid feed metal is always available for that portion that is just solidifying.

For the purposes of this specification, the term, '**Parting Line**' refers to the dividing line between mold halves. The top half of the mold is called **Cope** and the bottom half is called **Drag**.

For the purposes of this specification, the term, '**Mold**' or '**Mold box**' refers to a container into which molten liquid is poured to create a given shape when it hardens. The mold box material is typically made of sand. Other materials include: metallic molds.

For the purposes of this specification, the term, '**Voxels**' refers to an array of discrete elements into which a representation of a three-dimensional object is divided. Voxels are typically to represent three dimensional space. It can be used to identify whether a region in space is occupied by part/mould/is empty, etc.

For the purposes of this specification, the term, '**Surface Voxels**' refers to the voxels that are on the part surface and are visible to the mold box.

For the purposes of this specification, the term, '**STL**' refers to a triangular representation of a three-dimensional object.

For the purposes of this specification, the term, '**Undercuts**' refers to any indentation or protrusion in a shape that will prevent its withdrawal from a one-piece mold.

For the purposes of this specification, the term, '**Core**' refers to a device used in casting and molding processes to produce internal cavities and reentrant angles.

According to this invention, there is provided **a system and method for design analysis for metal casting design**.

Figure 1 illustrates a schematic block diagram of the system.

In accordance with an embodiment of this invention, there is provided an **input mechanism (IM)** adapted to receive at least an input file (F). Typically, the input file is a design file which comprises a designed geometry of the mold that is to be cast. Preferably, the input file is a CAD file and / or a corresponding triangulated representation of a CAD file.

In accordance with another embodiment of this invention, there is provided an **undercut identification mechanism (UIM)** adapted to identify undercut region(s) in the design of the input file. The undercut identification is based on principles of geometry and computational mechanism applied thereto. A part visibility technique is applied here. In at least an embodiment of the **undercut identification mechanism (UIM)**, there is provided a **voxelization mechanism** in order to voxelize part bounding box. Further, a **computation mechanism** computes a list of triangles intersecting with each voxel. A direction is specified, by means of a direction mechanism, and then a first associated voxel in the specified direction is computed, the association is in respect to at least a computed triangle. In other words, for a specified direction, say +Z, first associated voxel is computed i.e. voxel associated with at least one triangle for each X and Y value, starting from 0 if direction is positive, or last voxel in corresponding direction if direction is negative. For all the triangles associated with these voxels, if normal is directed opposite to the view direction, triangle is visible and all triangles which do not satisfy the above criteria, are obscured by default. Thus, the visible triangles form identified undercut region(s).

In accordance with yet another embodiment of this invention, there is provided a **parting line location mechanism (PLLM)** adapted to identify parting line location based on identified undercut region(s) and to identify parting line direction. For all surface voxels, it is determined, by means of a first determination mechanism, whether they are linked to identified undercut region(s) (or undercut surface). This is based on ray firing. Surface undercut voxels are combined into well-connected areas, by means of a second determination mechanism. For each identified undercut region(s), it is determined, by means of a third determination mechanism, whether they are internal or external undercut region(s), wherein a triangle is considered to be part of an internal undercut region if said triangle is obscure in both positive and negative directions of at least one orientation of said part. Visibility check helps to determine this. Internal undercuts are neglected. For all possible sections along major axes, undercut volume and area are calculated, by means of a second computation mechanism. Part orientation is computed, by means of a fourth determination mechanism, such that heavier section is in drag.

Figures 2, 3, 4, and 5 illustrate various steps of parting line analysis.

In at least a **first** embodiment, the location of the parting line is based on **identified undercut(s)**. Best possible parting line location is based on computed minimum undercut region(s). In at least an embodiment of the **parting position location mechanism (PPLM)**, there is provided a **minimum undercut parting direction mechanism** configured to define minimum undercut parting direction. A **visibility computation mechanism** computes visibility in all pre-defined directions. Typically, this is in all 6 +/- X/Y/Z directions. For each orientation (X/Y/Z), triangles which are not visible in both +ve and –ve direction are part of undercuts. Partial occlusion triangles are triangles not visible in at least 2 orientations, and are skipped during undercut computation. An area computation mechanism computes area(s) of undercuts in each orientation (X/Y/Z). This orientation is used with minimum undercut area as parting direction, in that, if more than one orientation has minimum undercut area, then the one with minimum draw is chosen as parting direction. This is done by means of a third computation mechanism.

In at least a **second** embodiment, the location of the parting line is based on **largest silhouette**. In at least an embodiment of the **parting line location mechanism (PLLM)**, there is provided a **maximum silhouette parting line mechanism** configured to provide a location of a parting line based on largest / maximum silhouette. A direction is specified, by means of a fifth determination mechanism, and for the chosen specified parting direction, the part co-ordinates are transformed, by means of a transformation mechanism, such that the Z-axis is oriented towards the corresponding chosen specified direction, and the X-axis and Y-axis is oriented towards the remaining two directions. A **maximum value computation mechanism** computes maximum X and Y values and corresponding Z co-ordinates. A **minimum value computation mechanism** computes minimum X and Y values and corresponding Z co-ordinates. If more than one Z-location has maximum / minimum X/Y value, the last such value is chosen. A **sectioning mechanism** sections the part at each of these Z-locations to form section plane(s). A **part edges' and vertices' computation mechanism** computes part edges and vertices at the section plane(s). A **2D bounding box computation mechanism** computes a 2D bounding box of each section plane(s) using maximum and minimum X and Y values which are computed from these vertices. A **comparator mechanism** compares and chooses a section(s) plane with maximum 2D bounding box area as parting line. A **loop formation mechanism** forms closed loops from the edges of the chosen 2D bounding box, until each edge has been used in a loop. A **parting line formation mechanism** forms and displays these loops of silhouette edges as parting line.

In at least one embodiment, there is provided a **selection mechanism** configured to choose sectioned plane(s) when multiple sectioned planes have maximum 2D bounding box areas, said selection mechanism being governed by pre-defined rules, said pre-defined rules comprise the steps of a) selecting sectioned plane(s) having planar faces normal to parting direction, b) selecting planar faces over cylindrical, c) selecting cylindrical faces with larger radii over those with smaller radii, selecting section closer to centroid of a given geometry if\n multiple sectioned planar faces exist;

In at least a **third** embodiment, the location of the parting line is based on **parting direction**. Direction is based on cope / drag weights. In at least an embodiment of the **parting line location mechanism (PLLM)**, is based on the part symmetry in multiple directions. A **part symmetricity computation mechanism** computes part symmetricity in X/Y/Z directions. A direction is specified and for the chosen specified parting direction, maximum and minimum values of the part bounding box dimension in the specific direction is computed. E.g. if the specified direction is Z, maximum and minimum Z in the part bounding box is computed. A **splitting mechanism** splits the part, midway, i.e. at a plane parallel to Z-axis and is located at (Zmax+Zmin)/2.

In at least one embodiment, a **split area computation mechanism** computes surface area of each of the two split parts. A **split area comparator mechanism** compares areas of the computed split parts, and if both the sectional or split areas are equal within tolerance, the part is considered symmetric in the corresponding or specified direction.

In at least another embodiment, a **symmetricity comparator mechanism** compares symmetricity of the part in more than one direction and if the part is symmetric in more than one direction, the direction with minimum draw is chosen as parting direction. Otherwise, parting direction is computed based on minimum external undercuts.

In at least one other embodiment, a - sixth computation mechanism configured to compute and select minimum draw based on 2D bounding box computation for each of the axes of symmetricity.

In at least a **fourth** embodiment, the location of the parting line is based on **metal and process of casting.**

In at least a **fifth** embodiment, the location of the parting line is based on the **face type** of the input file (designed geometry); i.e. whether it is planar, cylindrical, or the like.

In at least a **sixth** embodiment, the location of the parting line is based on **feed path to an identified hotspot.**

In at least an embodiment of the **parting line location mechanism (PLLM)**, there is provided a **minimum draw parting direction mechanism** configured to define minimum draw parting direction. At least a direction is specified and for each specified direction, part co-ordinates are transformed such that the Z-axis is oriented towards the corresponding chosen specified direction. A **maximum value computation mechanism** computes maximum Z values. A **minimum value computation mechanism** computes minimum Z values. A selection mechanism selects a direction with maximum value of (Zmax, Zmin) which is chosen as parting direction.

For a given geometry, three different parting lines or parting planes can be seen in Figures 7, 8, and 9 of the accompanying drawings. Red highlights are undercuts in each of the Figures 7, 8, and 9. Therefore, it can be seen that the parting plane that is optimum is that of Figure 9 of the accompanying drawings, which has minimum undercuts.

In accordance with still another embodiment of this invention, there is provided an **orientation defining mechanism (ODM)** adapted to define orientation of part (corresponding to the mould/casting assembly) to be placed for casting. This is based on pre-defined parameters relating to identification of undercut, identification of parting line, and the like parameters.

In at least one embodiment of the **orientation defining mechanism (ODM)**, there is provided a **part orientation mechanism** adapted to determine a part orientation. A parting line is chosen and for the chosen parting line, the part is transformed such that Z-axis points towards parting direction. The transformed co-ordinates of part vertices are used to compute maximum and minimum transformed Z-co-ordinates, and corresponding vertices are taken as extreme points from parting line. This parting line is drawn by means of a line drawing mechanism. A **vertices' distance computation mechanism** computes distance between these two vertices (maximum Z and minimum Z) from a parting line. A drag side determination mechanism comprises a comparator to determine a side with a relatively larger distance which is determined as the drag side. A cope side determination mechanism comprises a comparator to determine a side with a relatively smaller distance which is determined as the cope side.

In at least one other embodiment of the **orientation defining mechanism (ODM)**, there is provided a mechanism wherein a parting line is chosen and for the chosen parting line, the part is split and the weight of the part above and below the parting line is compared. A drag side determination mechanism comprises a comparator to compare the split parts in order to determine a drag side which has a relatively higher weight. A cope side determination mechanism comprises a comparator to compare the split parts in order to determine a cope side which has a relatively lower weight.

In at least one more other embodiment of the **orientation defining mechanism (ODM)**, the location of major hotspots (HS) is used to determine part orientation. A drag side determination mechanism comprises a comparator to compare the location of major hotspots in order to determine a drag side which has a relatively lower concentration of hotspots. A cope side determination mechanism comprises a comparator to compare the location of major hotspots in order to determine a cope side which has a relatively higher concentration of hotspots.

In accordance with still another embodiment of this invention, there is provided a **hot spots' identification mechanism (HSIM)** adapted to identify hot spots (HS) that may be possible in the designed geometry of the input file. The identification of hot spots is derived from computational analysis techniques comprising gradient vector methods (GVM). This mechanism is based on fundamental principles of heat transfer, cooling principles, flow of molten mass, thermodynamics, and the like. The casting solidifies progressively from the mold walls until it converges to isolated last solidifying points in the mold -cavity, known as hot-spots. The liquid-solid interface converges at hot-spots, forming a singularity. A hybrid Gradient Vector Method (GVM) was developed to compute the feed-paths by continuously tracing interface evolution with the help of mass-less particles in the normal direction. Location of the hot-spot was obtained as the point at which the advection of mass-less particles converged or in other words the point from where feed-paths originated.

A **temperature computation mechanism** computes temperature of the part voxels using Gradient Vector Method (GVM). Geometry of a part affects temperature distribution across the part. A **temperature normalization mechanism** is configured to normalize temperature of all the part voxels with respect to the maximum temperature among the part voxels, with maximum normalized temperature being 1 and minimum normalized temperature being 0. A **hotspot temperature cutoff definition mechanism** defines hotspot temperature cutoff as the ratio of materials solidus temperature to material liquidus temperature. All voxels are marked with normalized temperature greater than hotspot temperature cutoff as possible hotspot voxels. The hotspot voxels are combined. A hotspot is identified by a Hotspot Attribute. Volume of all the hotspots is determined. Volume is defined as the number of voxels marked with the Hotspot Attribute.

In at least one embodiment of this invention, there is provided a **processing mechanism** configured to perform the following steps:
- marking all voxels with normalized temperature greater than hotspot temperature cutoff as possible hotspot voxels;
- combining hotspot voxels;
- identifying a hotspot by means of a pre-defined hotspot attribute;
- determining volume of all hotspots; and
- defining volume as number of voxels marked with said pre-defined hotspot attribute.

In accordance with an additional embodiment of this invention, there is provided a **feeder modulus computation mechanism (FMCM)** adapted to compute feeder dimensions (FD) for the part that is to be cast. Feeder dimensions need to be optimized so that they are not oversized, yet feed the part. The system and method of this invention computes dimensions of feeder based on modulus values.
Modulus is defined as [Volume]/[Area]. Hence computation of modulus consists of two steps:
1. computation of area, by means of a feeder area computation mechanism; and

2. computation of volume, by means of a feeder volume computation mechanism.

1. For computation of area, by means of a processing mechanism, for each surface voxel,

   i. Proceed in the direction of temperature gradient till a hotspot voxel is reached.
   ii. If the hotspot is the one for which modulus is being computed, increase Area Count by 1

   area = [Area Count] * [Surface Area of one face of a voxel]

2. For computation of volume, this is simply determined as [Number of voxels having hotspot attribute] * [Volume of one voxel]

Typically, modulus of feeder is determined as a function of modulus of casting region and feeder design factor based on material.

Gradient: As defined in temperature computation

Modulus computation for each hotspot is done as follows:

i. For all voxels, determine the gradient along which the metal is expected to flow.
ii. Study all surface voxels to determine whose feed path converges in to the hotspot. This is used to determine surface area.
iii. Count all voxels – on the surface as well as those inside – that converge in to the hotspot. This is used to determine the volume.
iv. Modulus = volume/surface area
v. Feeder modulus = 1.2 * Modulus. Determine feeder dimensions accordingly. The value 1.2 is based on the material, process being used.
vi. Neck modulus = 1.1 * Modulus. Determine neck modulus accordingly. The value 1.1 is based on the material, process being used.

In at least one embodiment, feeder dimensions and position of feeder (whether side or top or angular) is determined by hotspot modulus.

Figure 6 illustrates steps relating to feeder placement and feeder dimensions.

In accordance with yet an additional embodiment of this invention, there is provided a **feeder positioning mechanism (FPM)** adapted to determine feeder position (FP) in relation to pre-determined parameters. After the feeder dimensions, feeder location is determined. This is done by taking the following factors in to account:

iv. Feed path – to effectively feed the hotspot

v. Fettleability – to place the feeder properly
vi. Intersection checks – to ensure feeder is not too close to the original part surface
vii. Directional solidification – to have defect free castings

In at least a first embodiment, fettleability is dependent upon feedpath to identified hotspot(s). In at least a second embodiment, fettleability is dependent upon face type of feeder. An economical practice is to attach feeders to flat faces or faces with large curvatures.

In at least an embodiment of the **feeder positioning mechanism (FPM)**, a **first evaluation mechanism** evaluates a hot spot region in order to identify the centroid and hottest temperature. Additionally, the part is evaluated, by means of a second evaluation mechanism, and analysed to look to flat areas so that fettling of feeder will not be a problem. Using this, the system and method of this invention can suggest a feeder position or a user can override the suggestion and manually locate a feeder position.

Typically, the following rules may be followed for identifying feeder placement faces for top and side feeder based on fettleability considerations:

- First priority: Planar faces
- Second priority: Cylindrical faces
- For each location, ensure that part thickness is more than feeder thickness by a factor of 1.5
- For hot spots closer to top of part, top feeders are preferred. Side feeders are unlikely.
- For hot spots closer to parting line, side feeders are preferred but top feeders are also ok
- Additional rules, like: for a pressure part, the side feeder is placed on cylindrical flange even though the flat face is available.

In accordance with still an additional embodiment of this invention, there is provided a **feeder geometry computation mechanism (FGCM)** adapted to compute feeder geometry based on pre-defined parameters relating to casting, relating to designed object, and relating to identified parameters of the object and casting.

In at least an embodiment of the **feeder geometry computation mechanism (FGCM)**, a **feeder dimension determination mechanism** determines feeder dimension(s) based on hotspot modulus. Typically, neck modulus is 1.2 times the hotspot modulus. Typically, feeder modulus is 1.4 times the hotspot modulus. Typically, depending on type of feeder (side/top), the neck is either rectangular or circular in cross section. Typically, the feeder is always cylindrical.

The solidification of the feeder must take place later than the nearest hot spot, expressed by the criterion:

$$M f = k f M h$$

Here, the modulus of the feeder is given by M f, the modulus of the casting region around the hot spot is given by M h and the feeder design factor, usually more than 1 (more than 1.1 for ductile iron casting, and more than 1.2 for Aluminium and steel casting) is given by k f. A larger factor might be needed (1.4 or more), if there is an intermediate section of casting between the feeder and the hot spot. It is to be noted that after connecting the feeder the modulus of the hot spot region will increase because the heat transfer area corresponding to the feeder neck would be reduced. Thus the feeder size must be further increased to take this into account.

In accordance with another additional embodiment of this invention, there is provided a **directional solidification analysis mechanism (DSAM)** adapted to indicate problem areas during casting.

v. For each part hotspot, section is taken with feeder
vi. A unique path is identified joining part hotspot and feeder hotspot
vii. Temperature along the path joining hotspot and feeder is analyzed to look at any undesired pattern. Rules are defined based on material, process, geometry inter-relationships.
viii. Changes in design suggested if required

In at least a first embodiment, directional solidification analysis is based upon temperature along path joining hotspots. Ideally, temperature should keep on rising from part to feeder hotspot. Else, minimum/maximum temperature should not have difference of more than 300C. In at least a second embodiment, directional solidification analysis is based upon length of part. Even with expected temperature graph, directional solidification may not happen if length along the graph is large.

Directional solidification is determined in the following steps, for each hotspot:

1. If part volume of the hotspot is zero, direction solidification is occurring.
2. Associate the nearest feeder hotspot as Feeder Hotspot. This may or may not be connected with the hotspot being iterated.
3. Estimate the shortest path joining core of part hotspot and core of feeder hotspot along the skeleton. Skeleton is computed using Palagyi's technique. This is done by defining the nearest voxel on skeleton as end points and using Dijkstra's technique to find the shortest path.

4. If along the path, if at any voxel – the difference between voxel temperature and end point temperature is more than 300C, then consider the hotspot as not being fed – directional solidification is not occurring.

Figure 10 illustrates hotspots at highest threshold of hotspot. Reference numerals 1, 2, 3, and 4 are hotspots wherein hotspots 1, 3, and 4 are hotspots near to parting line (plane) and hotspots 2 and 3 are in cope. Therefore, feeder placement, according to this invention, for the part of Figure 10, is as follows:

Hot Spot #	Cope, Drag, Both	Near to Parting Line	Top Feeder	Side Feeder
1	Both	Yes	Possible	Possible
2	Cope	No	Yes	No
3	Cope	Yes	Very Difficult	No
4	Both	Yes	Possible	Possible

Furthermore, Figure 11 illustrates feed path direction (reference numeral FPD) at a hotspot 1 of the part of Figure 10.

Hotspot Number	Feeder Modulus	Top/Side	Fettlable	Directional problem
1	10.34	Top	Yes	No
2	12.19	Top	Yes	No
3		No Feeder	No	Yes
4	10.34	Top	Yes	No

The data, in each of the components, means, modules, mechanisms, units, devices of the system and method may be 'encrypted' and suitably 'decrypted' when required.

The systems described herein can be made accessible through a portal or an interface which is a part of, or may be connected to, an internal network or an external network, such as the Internet or any similar portal. The portals or interfaces are accessed by one or more of users through an electronic device, whereby the user may send and receive data to the portal or interface which gets stored in at least one memory device or at least one data storage device or at least one server, and utilises at least one processing unit. The portal or interface in combination with one or more of memory device, data storage device, processing unit and serves, form an embedded computing setup, and may be used by, or used in, one or more of a non-transitory, computer readable medium. In at least one embodiment, the embedded computing setup and optionally one or more of a non-transitory, computer readable medium, in relation with, and in combination with the said portal or interface forms one of the systems of the invention. Typical examples of a portal or interface may be selected from but is not limited to a website, an executable software program or a software application.

The systems and methods may simultaneously involve more than one user or more than one data storage device or more than one host server or any combination thereof.

A user may provide user input through any suitable input device or input mechanism such as but not limited to a keyboard, a mouse, a joystick, a touchpad, a virtual keyboard, a virtual data entry user interface, a virtual dial pad, a software or a program, a scanner, a remote device, a microphone, a webcam, a camera, a fingerprint scanner, a cave, pointing stick

The systems and methods can be practiced using any electronic device which may be connected to one or more of other electronic device with wires or wirelessly which may use technologies such as but not limited to, NFC, Bluetooth, Wi-Fi, Wimax. This will also extend to use of the aforesaid technologies to provide an authentication key or access key or electronic device based unique key or any combination thereof.

In at least one embodiment, one or more user can be blocked or denied access to one or more of the aspects of the invention.

Encryption can be accomplished using any encryption technology, such as the process of converting digital information into a new form using a key or a code or a program, wherein the new form is unintelligible or indecipherable to a user or a thief or a hacker or a spammer. The term ‘encryption’ includes encoding, compressing, or any other translating of the digital content. The encryption of the digital media content can be performed in accordance with any technology including utilizing an encryption algorithm. The encryption algorithm utilized is not hardware dependent and may change depending on the digital content. For example, a different algorithm may be utilized for different websites or programs. The term ‘encryption’ further includes one or more aspects of authentication, entitlement, data integrity, access control, confidentiality, segmentation, information control, and combinations thereof.

The described embodiments may be implemented as a system, method, apparatus or article of manufacture using standard programming and/or engineering techniques related to software, firmware, hardware, or any combination thereof. The described operations may be implemented as code maintained in a "non-transitory, computer readable medium", where a processor may read and execute the code from the non-transitory, computer readable medium. A non-transitory, computer readable medium may comprise media such as magnetic storage medium (e.g., hard disk drives, floppy disks, tape, etc.), optical storage (CD-ROMs, DVDs, optical disks, etc.), volatile and non-volatile memory devices (e.g., EEPROMs, ROMs, PROMs, RAMs, DRAMs, SRAMs, Flash Memory, firmware, programmable logic, etc.), etc. The code implementing the described operations may further be implemented in hardware logic (e.g., an integrated circuit chip, Programmable Gate Array (PGA), Application Specific Integrated Circuit (ASIC), etc.).

Still further, the code implementing the described operations may be implemented in "transmission signals", where transmission signals may propagate through space or through a transmission media, such as an optical fibre, copper wire, etc. The transmission signals in which the code or logic is encoded may further comprise a wireless signal, satellite transmission, radio waves, infrared signals, Bluetooth, etc. The transmission signals in which the code or logic is encoded is capable of being transmitted by a transmitting station and received by a receiving station, where the code or logic encoded in the transmission signal may be decoded and stored in hardware or a non-transitory, computer readable medium at the receiving and transmitting stations or devices. An "article of manufacture" comprises non-transitory, computer readable medium or hardware logic, and/or transmission signals in which code may be implemented. A device in which the code implementing the described embodiments of operations is encoded may comprise a non-transitory, computer readable medium or hardware logic. Of course, those skilled in the art will recognize that many modifications may be made to this configuration without departing from the scope of the present invention, and that the article of manufacture may comprise suitable information bearing medium known in the art.

The term network means a system allowing interaction between two or more electronic devices, and includes any form of inter/intra enterprise environment such as the world wide web, Local Area Network (LAN) , Wide Area Network (WAN) , Storage Area Network (SAN) or any form of Intranet.

The systems and methods can be practiced using any electronic device. An electronic device for the purpose of this invention is selected from any device capable of processing or representing data to a user and providing access to a network or any system similar to the internet, wherein the electronic device may be selected from but not limited to, personal computers, tablet computers, mobile phones, laptop computers, palmtops, portable media players, and personal digital assistants. In an embodiment, the computer readable medium data storage unit or data storage device is selected from a set of but not limited to USB flash drive (pen drive), memory card, optical data storage discs, hard disk drive, magnetic disk, magnetic tape data storage device, data server and molecular memory.

The process steps, method steps, algorithms or the like may be described in a sequential order, such processes, methods and algorithms may be configured to work in alternate orders. In other words, any sequence or order of steps that may be described does not necessarily indicate a requirement that the steps be performed in that order. The steps of processes described herein may be performed in any order practical. Further, some steps may be performed simultaneously, in parallel, or concurrently.

While the present invention is susceptible of embodiment in various forms, there is shown in the drawings and will hereinafter be described a presently preferred embodiment with the understanding that the present disclosure is to be considered an exemplification of the invention and is not intended to limit the invention to the specific embodiments illustrated. The use of "including", "comprising" or "having" and variations thereof herein is meant to encompass the items listed thereafter and equivalents thereof as well as additional items.

The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. As used herein, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises" and/or "comprising," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude or rule out the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

While this detailed description has disclosed certain specific embodiments for illustrative purposes, various modifications will be apparent to those skilled in the art which do not constitute departures from the spirit and scope of the invention as defined in the following claims, and it is to be distinctly understood that the foregoing descriptive matter is to be interpreted merely as illustrative of the invention and not as a limitation.

Claims,

1. A system for design analysis for metal casting design of a part to be cast, said system comprising:
   i. input mechanism adapted to receive at least an input file relating to said part, said input file being a set of triangles which represent said part;
   ii. undercut identification mechanism adapted to identify undercut region(s) in the design of the input file;
   iii. parting line location mechanism adapted to identify parting line location based on identified undercut region(s) and to identify parting line direction;
   iv. orientation defining mechanism adapted to define orientation of part (corresponding to the mold/casting assembly) to be placed for casting;
   v. hot spots' identification mechanism adapted to identify hotspots that may be possible in the designed geometry of the input file;
   vi. feeder modulus computation mechanism adapted to compute feeder dimensions for the part that is to be cast based on identified hotspots;
   vii. feeder positioning mechanism adapted to determine feeder position in relation to pre-determined parameters; and
   viii. directional solidification analysis mechanism adapted to problem areas related to directional solidification, shrinkage porosity during casting solidification.

2. A system for design analysis for metal casting design as claimed in claim 1 wherein, said undercut identification mechanism comprising a voxelization mechanism configured to voxelize mold box and further comprising a first

computation mechanism configured to compute a list of triangles intersecting with each voxel, characterised in that, a direction mechanism being configured to choose a direction and then computing a first associated voxel in said chosen direction, said association being in respect to at least a computed triangle further wherein for all the triangles associated with these voxels, if normal is directed opposite to the view direction, triangle is visible and all triangles which do not satisfy the above criteria, are obscured by default, thereby forming identified potential undercut region(s) from said visible triangles.

3. A system for design analysis for metal casting design as claimed in claim 1 wherein, said parting line location mechanism comprising:
    i. first determination mechanism configured to determine whether all surface voxels are linked to identified region(s);
    ii. second determination mechanism configured to determine if surface undercut voxels are combined into well-connected areas;
    iii. third determination mechanism configured to determine if each identified undercut region is an internal undercut region or an external undercut region, wherein a triangle is considered to be part of an internal undercut region if said triangle is obscure in both positive and negative directions of at least one orientation of said part;
    iv. second computation mechanism configured to compute undercut volume and undercut area for all possible external undercuts along major axes; and
    v. fourth determination mechanism in order to determine part orientation based on computed undercut volume and computed undercut area, characterised in that, a drag part of said mold being a relatively heavier part and a cope part of said mold being a relatively lighter part.

4. A system for design analysis for metal casting design as claimed in claim 1 wherein, said parting line location mechanism comprising:
   i. minimum undercut parting direction mechanism configured to define minimum undercut parting direction;
   ii. visibility computation mechanism configured to compute visibility in all pre-defined directions;
   iii. area computation mechanism configured to compute area(s) of undercuts in each orientation; and
   iv. third computation mechanism configured to compute and select minimum draw as parting direction if more than one orientation has minimum undercut area.

5. A system for design analysis for metal casting design as claimed in claim 1 wherein, said parting line location mechanism comprising:
   i. maximum silhouette parting line mechanism configured to provide a location of a parting line based on largest / maximum silhouette;
   ii. fifth determination mechanism configured to determine a parting direction;
   iii. transformation mechanism configured to transform co-ordinates of said mold design based on determined parting direction such that Z-axis is oriented towards the corresponding chosen direction, and X-axis and Y-axis is oriented towards remaining two directions;
   iv. maximum value computation mechanism configured to compute maximum X and Y values and corresponding Z co-ordinates;
   v. minimum value computation mechanism configured to compute minimum X and Y values and corresponding Z co-ordinates;

vi. sectioning mechanism configured to section the part at each of these Z-locations to form sectioned plane(s);

vii. part edges' and vertices' computation mechanism configured to compute part edges and vertices at said sectioned plane;

viii. 2D bounding box computation mechanism configured to compute a 2D bounding box of each sectioned plane(s) using maximum and minimum X and Y values which are computed from these vertices;

ix. comparator mechanism configured to compare and choose a sectioned plane with maximum 2D bounding box area as parting line;

characterised in that, when there are multiple sectioned plane(s) in said 2D bounding box, said system further comprising:

selection mechanism configured to choose sectioned plane(s) when multiple sectioned planes have maximum 2D bounding box areas, said selection mechanism being governed by pre-defined rules, said pre-defined rules comprising the steps of a) selecting sectioned plane(s) having planar faces normal to parting direction, b) selecting planar faces over cylindrical, c) selecting cylindrical faces with larger radii over those with smaller radii, selecting section closer to centroid of a given geometry if multiple sectioned planar faces exist;

x. loop formation mechanism configured to form closed loops from all the edges of said chosen 2D bounding box; and

xi. parting line formation mechanism configured to form and display said loops of silhouette edges as parting line.

6. A system for design analysis for metal casting design as claimed in claim 1 wherein, said parting line location mechanism comprising:

i. part symmetricity computation mechanism configured to compute part symmetricity in all directions;
ii. fifth determination mechanism configured to determine a parting direction;
iii. transformation mechanism configured to transform co-ordinates of said mold design based on determined parting direction such that Z-axis is oriented towards the corresponding chosen direction, and X-axis and Y-axis is oriented towards remaining two directions;
iv. maximum value computation mechanism configured to compute maximum X and Y values and corresponding Z co-ordinates;
v. minimum value computation mechanism configured to compute minimum X and Y values and corresponding Z co-ordinates;
vi. sectioning mechanism configured to section the part at each of these Z-locations to form sectioned plane(s);
vii. part edges' and vertices' computation mechanism configured to compute part edges and vertices at said sectioned plane;
viii. 2D bounding box computation mechanism configured to compute a 2D bounding box of each section plane(s) using maximum and minimum X and Y values which are computed from these vertices;
ix. symmetricity comparator mechanism configured to compare symmetricity of the part in more than one direction and if the part is symmetric in more than one direction, the direction with minimum draw is chosen as parting direction otherwise the direction with minimum external undercuts is chosen as parting direction; and
x. sixth computation mechanism configured to compute and select minimum draw based on 2D bounding box computation for each of the axes of symmetricity.

7. A system for design analysis for metal casting design as claimed in claim 1 wherein, said parting line location mechanism comprising mechanisms to locate parting line based on feed path to an identified hotspot.

8. A system for design analysis for metal casting design as claimed in claim 1 wherein, said parting line location mechanism comprising:
   i. minimum draw parting direction mechanism configured to define minimum draw parting direction;
   ii. transformation mechanism configured to transform co-ordinates of said mold design based on determined parting direction such that Z-axis is oriented towards the corresponding chosen direction, and X-axis and Y-axis is oriented towards remaining two directions;
   iii. maximum value computation mechanism configured to compute maximum Z values;
   iv. minimum value computation mechanism configured to compute minimum maximum Z values; and
   v. selection mechanism configured to select a direction with maximum value selected from computed minimum Z values and maximum Z values which is chosen as parting direction.

9. A system for design analysis for metal casting design as claimed in claim 1 wherein, said orientation defining mechanism comprising:
   i. part orientation mechanism configured to determine a part orientation;
   ii. transformation mechanism configured to transform co-ordinates of said mold design based on determined parting direction such that Z-axis is oriented towards the corresponding chosen direction, and X-axis and Y-axis is oriented towards remaining two directions;

iii. maximum value computation mechanism configured to compute maximum X and Y values and corresponding Z co-ordinates;

iv. minimum value computation mechanism configured to compute minimum X and Y values and corresponding Z co-ordinates;

v. line drawing mechanism configured to draw at least a parting line wherein corresponding vertices are taken as extreme points from parting line;

vi. vertices' distance computation mechanism configured to compute distance between these two vertices (maximum Z and minimum Z) from a parting line; and

vii. drag side determination mechanism comprising a comparator to determine a side with a relatively larger distance in order to determine it as drag side; and

viii. cope side determination mechanism comprising a comparator to determine a side with a relatively smaller distance in order to determine it as cope side.

10. A system for design analysis for metal casting design as claimed in claim 1 wherein, said orientation defining mechanism comprising:

i. part orientation mechanism configured to determine a part orientation;

ii. transformation mechanism configured to transform co-ordinates of said mold design based on determined parting direction such that Z-axis is oriented towards the corresponding chosen direction, and X-axis and Y-axis is oriented towards remaining two directions;

iii. maximum value computation mechanism configured to compute maximum X and Y values and corresponding Z co-ordinates;

iv. minimum value computation mechanism configured to compute minimum X and Y values and corresponding Z co-ordinates;

v. line drawing mechanism configured to draw at least a parting line wherein corresponding vertices are taken as extreme points from parting line;
vi. splitting mechanism configured to split the part and compare weight of the part above and below the parting line;
vii. weight comparator mechanism configured to compare and determine a side with a relatively higher weight in order to determine it as drag side; and
viii. weight comparator mechanism configured to compare and determine a side with a relatively lower weight distance in order to determine it as cope side.

11. A system for design analysis for metal casting design as claimed in claim 1 wherein, said orientation defining mechanism comprising:
i. part orientation mechanism configured to determine a part orientation;
ii. transformation mechanism configured to transform co-ordinates of said mold design based on determined parting direction such that Z-axis is oriented towards the corresponding chosen direction, and X-axis and Y-axis is oriented towards remaining two directions;
iii. maximum value computation mechanism configured to compute maximum X and Y values and corresponding Z co-ordinates;
iv. minimum value computation mechanism configured to compute minimum X and Y values and corresponding Z co-ordinates;
v. line drawing mechanism configured to draw at least a parting line wherein corresponding vertices are taken as extreme points from parting line;
vi. comparator mechanism configured to compare and determine a side with a relatively lower concentration of hotspots in order to determine it as drag side; and

vii. comparator mechanism configured to compare and determine a side with a relatively higher concentration of hotspots in order to determine it as cope side.

12.A system for design analysis for metal casting design as claimed in claim 1 wherein, said system comprising:

i. temperature computation mechanism configured to compute temperature of part voxels using Gradient Vector Method;

ii. temperature normalization mechanism configured to normalize temperature of all part voxels with respect to the maximum temperature among said part voxels, with maximum normalized temperature being 1 and minimum normalized temperature being 0; and

iii. hotspot temperature cutoff definition mechanism configured to define hotspot temperature cutoff as the ratio of materials solidus temperature to material liquidus temperature; and

iv. a processing mechanism configured to perform the following steps:

a) marking all voxels with normalized temperature greater than hotspot temperature cutoff as possible hotspot voxels;

b) combining hotspot voxels and identifying a hotspot by means of a pre-defined hotspot attribute;

c) identifying a hotspot by means of a pre-defined hotspot attribute;

d) determining volume of all hotspots;

e) defining volume as number of voxels marked with said pre-defined hotspot attribute;

f) computing area for each surface voxel by performing a first step proceeding in the direction of temperature gradient till a hotspot voxel is reached, and further performing a second step of increasing area count by a factor if the hotspot is the one for which modulus is being computed, wherein area is computed by multiplying area count by surface area of each voxel;

g) computing volume by multiplying number of voxels having hotspot attribute with volume of voxel;

h) computing modulus as a ratio of computed volume to computed surface area;

i) computing feeder modulus as a factor of computed modulus, thereby determining feeder dimensions, accordingly, said factor being selected based on material and process being used; and

j) computing neck modulus as a factor of computed modulus, said factor being selected based on material and process being used.

13. A system for design analysis for metal casting design as claimed in claim 1 wherein, said feeder positioning mechanism comprising a processing mechanism configured to perform the following steps in order to determine feeder position:

i. evaluating a hot spot region in order to identify the centroid and hottest temperature;

ii. determining feed path in order to effectively feed the hotspot; and

iii. determining directional solidification in order to have defect free castings.

14. A system for design analysis for metal casting design as claimed in claim 1 wherein, said feeder positioning mechanism comprising a processing mechanism configured to perform the following steps in order to determine feeder position:

i. determining fettleability in order to place the feeder properly;

ii. determining intersection checks in order to ensure feeder is not too close to the original part surface; and

iii. evaluating and analysing flat areas for fettling relating issues.

15. A system for design analysis for metal casting design ad claimed in claim 1 wherein, said feeder positioning mechanism comprising a processing mechanism configured to determine position of feeder based on following rules:

i. giving planar faces first priority;

ii. giving cylindrical faces second priority;

iii. for each location, ensuring that part thickness is more than feeder thickness by a pre-determined factor;

iv. for hot spots closer to top of part, preferring top feeders; and

v. for hot spots closer to parting line, preferring side feeders.

16. A system for design analysis for metal casting design as claimed in claim 1 wherein, said system further comprising a feeder geometry computation mechanism configured to compute feeder geometry based on pre-defined parameters relating to casting, relating to designed part, and relating to identified parameters of the mold and casting, said feeder geometry computation mechanism comprising:

i. determination mechanism configured to determine feeder dimension(s) based on hotspot modulus;

ii. determination mechanism configured to determine feeder dimension(s) based on hotspot modulus, characterised in that, said neck modulus is a pre-determined factor of hotspot modulus;

iii. determination mechanism configured to determine feeder dimension(s) based on hotspot modulus, said feeder modulus is a pre-determined factor of hotspot modulus; and

iv. determination mechanism configured to determine feeder dimension(s) based on hotspot modulus, said modulus of feeder being determined as a function of modulus of casting region and feeder design factor based on material

17. A system for design analysis for metal casting design as claimed in claim 1 wherein, said directional solidification analysis mechanism comprising a processing mechanism configured to perform the following steps:

i. for each part hotspot, section being taken with feeder;

ii. a unique path being identified for joining part hotspot and feeder hotspot;

iii. temperature along the path joining hotspot and feeder being analyzed to look at any undesired pattern based on rules that are defined based on material, process, geometry inter-relationships; and

iv. iterating changes in design if required.

18. A system for design analysis for metal casting design as claimed in claim 1 wherein, said directional solidification analysis mechanism comprising a processing mechanism configured to perform the following steps, for each hotspot:

i. determining that if volume of the hotspot in part is zero, then direction solidification is occurring;

ii. associating nearest feeder hotspot as feeder hotspot;

iii. estimating a shortest path joining core of part hotspot and core of feeder hotspot along a skeleton, said skeleton being computed using Palagyi's technique by defining the nearest voxel on skeleton as end points and using computationally efficient technique to find the shortest path; and

iv. determining that if along the path, if at any voxel, the difference between voxel temperature and end point temperature is more than a predefined temperature then considering the hotspot as not being fed and therefore determining that directional solidification is not occurring.

19.A method for design analysis for metal casting design of a part to be cast, said method comprising the steps of:

i. receiving at least an input file relating to said part, said input file being a set of triangles which represent said part;

ii. identifying undercut region(s)in the design of the input file;

iii. identifying parting line location based on identified undercut region(s)and to identify parting line direction;

iv. defining orientation of object (corresponding to the mold/casting assembly) to be placed for casting;

v. identifying hotspots that may be possible in the designed geometry of the input file;

vi. computing feeder dimensions for the object that is to be cast based on identified hotspots;

vii. determining feeder position in relation to pre-determined parameters; and

viii. indicating problem areas related to directional solidification, shrinkage porosity during casting solidification.

20.A method for design analysis for metal casting design as claimed in claim 19 wherein, said identifying undercut region(s) in the design of the input file further comprising a step of voxelizing mold box and further comprising a step of computing a list of triangles intersecting with each voxel, characterised in that, said method being characterised by providing a further step of choosing a direction and then computing a first associated voxel in said chosen direction, said association being in respect to at least a computed triangle further wherein for all the triangles associated with these voxels, if normal is directed opposite to the view direction, triangle is visible and all triangles which do not satisfy the above criteria, are obscured by default, thereby forming identified potential undercut region(s)from said visible triangles.

21. A method for design analysis for metal casting design as claimed in claim 19 wherein, said step of identifying parting line location further comprising the steps of:

i. determining whether all surface voxels are linked to identified region(s);
ii. determining if surface undercut voxels are combined into well-connected areas;
iii. determining if each identified undercut region is an internal undercut region or an external undercut region, wherein a triangle is considered to be part of an internal undercut region if said triangle is obscure in both positive and negative directions of at least one orientation of said part;
iv. computing undercut volume and undercut area for all possible external undercuts along major axes; and
v. determining part orientation based on computed undercut volume and computed undercut area, characterised in that, a drag part of said mold being a relatively heavier part and a cope part of said mold being a relatively lighter part.

22. A method for design analysis for metal casting design as claimed in claim 19 wherein, said step of identifying parting line location further comprising the steps of:

   i. defining minimum undercut parting direction;
   ii. computing visibility in all pre-defined directions;
   iii. computing area(s) of undercuts in each orientation; and
   iv. computing and selecting minimum draw as parting direction if more than one parting direction has minimum undercut area.

23. A method for design analysis for metal casting design as claimed in claim 19 wherein, said step of identifying parting line location further comprising the steps of:

   i. providing a location of a parting line based on largest / maximum silhouette;
   ii. determining a parting direction;
   iii. transforming co-ordinates of said mold design based on determined parting direction such that Z-axis is oriented towards the corresponding chosen direction, and computing maximum and minimum X and Y values and corresponding Z values;
   iv. sectioning the part at each of these Z-locations to form sectioned plane(s), and computing part edges and vertices at said sectioned plane;
   v. computing a 2D bounding box of each sectioned plane(s) using maximum and minimum X and Y values which are computed from these vertices;
   vi. comparing and choosing a sectioned plane with maximum 2D bounding box area as parting line;

   characterised in that, when there are multiple sectioned plane(s) in said 2D bounding box, said method further comprising the steps of:

choosing sectioned plane(s) when multiple sectioned planes have maximum 2D bounding box areas, said selection mechanism being governed by pre-defined rules, said pre-defined rules comprising the steps of a) selecting sectioned plane(s) having planar faces normal to parting direction, b) selecting planar faces over cylindrical, c) selecting cylindrical faces with larger radii over those with smaller radii, selecting section closer to centroid of a given geometry if multiple sectioned planar faces exist;

vii. forming closed loops from all the edges of said chosen 2D bounding box; and

viii. forming and displaying said loops of silhouette edges as parting line.

24. A method for design analysis for metal casting design as claimed in claim 19 wherein, said step of identifying parting line location further comprising the steps of:

i. computing part symmetricity in all directions;

ii. determining a parting direction;

iii. transforming co-ordinates of said mold design based on determined parting direction such that Z-axis is oriented towards the corresponding chosen direction, and computing maximum and minimum X and Y values and corresponding Z values;

iv. sectioning the part at each of these Z-locations to form sectioned plane(s);

v. computing part edges and vertices at said sectioned plane;

vi. computing 2D bounding box of each section plane(s) using maximum and minimum X and Y values which are computed from these vertices;

vii. comparing symmetricity of the part in more than one direction and if the part is symmetric in more than one direction, the direction with minimum draw is chosen as parting direction otherwise the direction with minimum external undercuts is chosen as parting direction; and

viii. computing and selecting minimum draw based on 2D bounding box computation for each of the axes of symmetricity.

25. A method for design analysis for metal casting design as claimed in claim 19 wherein, said step of identifying parting line location further comprising a step of locating parting line based on feed path to an identified hotspot.

26. A method for design analysis for metal casting design as claimed in claim 19 wherein, said step of identifying parting line location further comprising the steps of:

i. defining minimum draw parting direction;
ii. transforming co-ordinates of said mold design based on determined parting direction such that Z-axis is oriented towards the corresponding chosen direction, and X-axis and Y-axis is oriented towards remaining two directions;
iii. computing maximum Z values;
iv. computing minimum Z values; and
v. selecting a direction with maximum value selected from computed minimum Z values and maximum Z values which is chosen as parting direction.

27. A method for design analysis for metal casting design as claimed in claim 19 wherein, said defining orientation of part (corresponding to the mold/casting assembly) to be placed for casting comprising the steps of:

i. determining a part orientation;

ii. transforming co-ordinates of said mold design based on determined parting direction such that Z-axis is oriented towards the corresponding chosen direction, and X-axis and Y-axis is oriented towards remaining two directions;

iii. computing maximum X and Y values and corresponding Z co-ordinates;

iv. computing minimum X and Y values and corresponding Z co-ordinates;

v. drawing at least a parting line wherein corresponding vertices are taken as extreme points from parting line;

vi. computing distance between these two vertices (maximum Z and minimum Z) from a parting line; and

vii. comparing to determine a side with a relatively larger distance in order to determine it as drag side; and

viii. comparing to determine a side with a relatively smaller distance in order to determine it as cope side.

28. A method for design analysis for metal casting design as claimed in claim 19 wherein, said defining orientation of part (corresponding to the mold/casting assembly) to be placed for casting comprising the steps of:

i. determining a part orientation;

ii. transforming co-ordinates of said mold design based on determined parting direction such that Z-axis is oriented towards the corresponding chosen direction, and X-axis and Y-axis is oriented towards remaining two directions;

iii. computing maximum X and Y values and corresponding Z co-ordinates;

iv. computing minimum X and Y values and corresponding Z co-ordinates;

v. drawing at least a parting line wherein corresponding vertices are taken as extreme points from parting line;

vi. splitting the part and comparing weight of the part above and below the parting line is compared;

vii. comparing to determine a side with a relatively higher weight in order to determine it as drag side; and

viii. comparing to determine a side with a relatively lower weight distance in order to determine it as cope side.

29. A method for design analysis for metal casting design as claimed in claim 19 wherein, said defining orientation of part (corresponding to the mold/casting assembly) to be placed for casting comprising the steps of:

i. determining a part orientation;

ii. transforming co-ordinates of said mold design based on determined parting direction such that Z-axis is oriented towards the corresponding chosen direction, and X-axis and Y-axis is oriented towards remaining two directions;

iii. computing maximum X and Y values and corresponding Z co-ordinates;

iv. computing minimum X and Y values and corresponding Z co-ordinates;

v. drawing at least a parting line wherein corresponding vertices are taken as extreme points from parting line;

vi. comparing to determine a side with a relatively lower concentration of hotspots in order to determine it as drag side; and

vii. comparing to determine a side with a relatively higher concentration of hotspots in order to determine it as cope side.

30. A method for design analysis for metal casting design as claimed in claim 19 wherein, said method comprising the steps of:

i. computing temperature of part voxels using Gradient Vector Method;

ii. normalizing temperature of all part voxels with respect to the maximum temperature among said part voxels, with maximum normalized temperature being 1 and minimum normalized temperature being 0;

iii. defining hotspot temperature cutoff as the ratio of materials solidus temperature to material liquidus temperature;

iv. marking all voxels with normalized temperature greater than hotspot temperature cutoff as possible hotspot voxels;

v. combining hotspot voxels and identifying a hotspot by means of a pre-defined hotspot attribute;

vi. computing area for each surface voxel by performing a first step proceeding in the direction of temperature gradient till a hotspot voxel is reached, and further performing a second step of increasing area count by a factor if the hotspot is the one for which modulus is being computed, wherein area is computed by multiplying area count by surface area of each voxel;

vii. computing volume by multiplying number of voxels having hotspot attribute with volume of voxel;

viii. computing modulus as a ratio of computed volume to computed surface area;

ix. computing feeder modulus as a factor of computed modulus, thereby determining feeder dimensions, accordingly, said factor being selected based on material and process being used; and

x. computing neck modulus as a factor of computed modulus, said factor being selected based on material and process being used being selected based on material and process being used.

31. A method for design analysis for metal casting design as claimed in claim 19 wherein, said step of determining feeder position in relation to pre-determined

parameters further comprising the following steps in order to determine feeder position:

i. evaluating a hot spot region in order to identify the centroid and hottest temperature;

ii. determining feed path in order to effectively feed the hotspot; and

iii. determining directional solidification in order to have defect free castings.

32. A method for design analysis for metal casting design as claimed in claim 19 wherein, said step of determining feeder position in relation to pre-determined parameters further comprising the following steps in order to determine feeder position:

i. determining fettleability in order to place the feeder properly;

ii. determining intersection checks in order to ensure feeder is not too close to the original part surface; and

iii. evaluating and analysing flat areas for fettling relating issues.

33. A method for design analysis for metal casting design ad claimed in claim 19 wherein, said step of determining feeder position in relation to pre-determined parameters being based on following rules:

i. giving planar faces first priority;

ii. giving cylindrical faces second priority;

iii. for each location, ensuring that part thickness is more than feeder thickness by a pre-determined factor;

iv. for hot spots closer to top of part, preferring top feeders; and

v. for hot spots closer to parting line, preferring side feeders are preferred.

34. A method for design analysis for metal casting design as claimed in claim 19 wherein, said method further comprising a step of computing feeder geometry based on pre-defined parameters relating to casting, relating to designed part, and relating to identified parameters of the mold and casting, further wherein:

   i. said step of determining feeder dimension(s) is based on hotspot modulus;
   ii. said step of determining feeder dimension(s) comprising a step of determining feeder dimension(s) is based on hotspot modulus, characterised in that, said neck modulus is a pre-determined factor of hotspot modulus;
   iii. said step of determining feeder dimension(s) is based on hotspot modulus, characterised in that, said feeder modulus is a pre-determined factor of hotspot modulus;
   iv. said step of computing feeder dimensions for the part that is to be cast is based on identified hotspots, characterised in that, said modulus of feeder being determined as a function of modulus of casting region and feeder design factor based on material

35. A method for design analysis for metal casting design as claimed in claim 19 wherein, said step of indicating problem areas during casting further comprising the following steps:

   i. for each part hotspot, section being taken with feeder;
   ii. a unique path being identified for joining part hotspot and feeder hotspot;
   iii. temperature along the path joining hotspot and feeder being analyzed to look at any undesired pattern based on rules that are defined based on material, process, geometry inter-relationships; and
   iv. iterating changes in design if required.

36. A method for design analysis for metal casting design as claimed in claim 19 wherein, said step of indicating problem areas during casting further comprising the following steps, for each hotspot:

i. determining that if volume of the hotspot in partis zero, then direction solidification is occurring;
ii. associating nearest feeder hotspot as feeder hotspot;
iii. estimating a shortest path joining core of part hotspot and core of feeder hotspot along a skeleton, said skeleton being computed using Palagyi's technique by defining the nearest voxel on skeleton as end points and using computationally efficient technique to find the shortest path; and
iv. determining that if along the path, if at any voxel, the difference between voxel temperature and end point temperature is more than a predefined temperature then considering the hotspot as not being fed and therefore determining that directional solidification is not occurring.

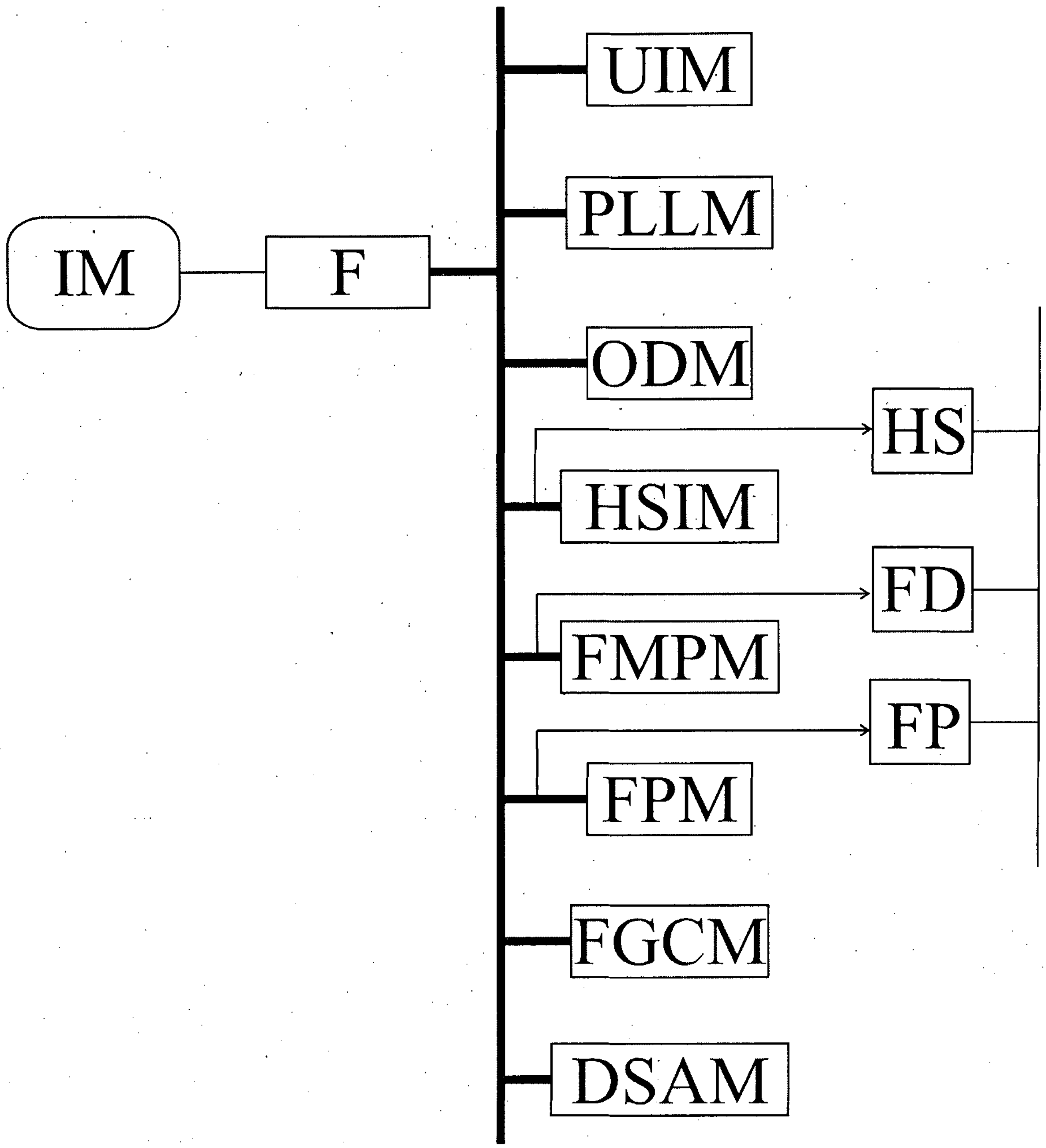

FIGURE 1

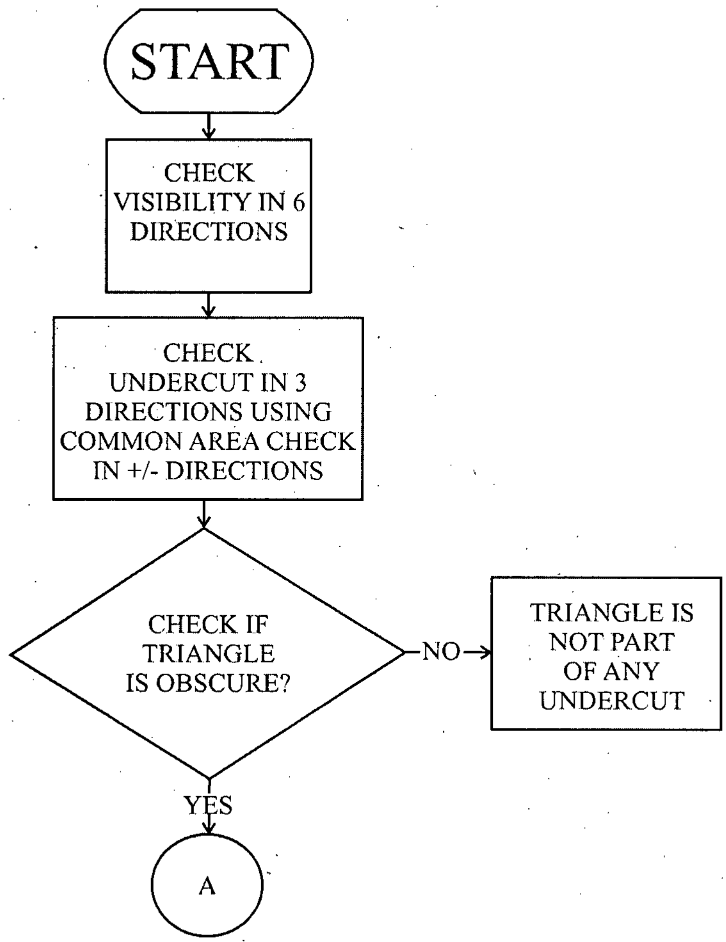
START
CHECK VISIBILITY IN 6 DIRECTIONS
CHECK UNDERCUT IN 3 DIRECTIONS USING COMMON AREA CHECK IN +/- DIRECTIONS
CHECK IF TRIANGLE IS OBSCURE?
NO
TRIANGLE IS NOT PART OF ANY UNDERCUT
YES
A

FIGURE 2

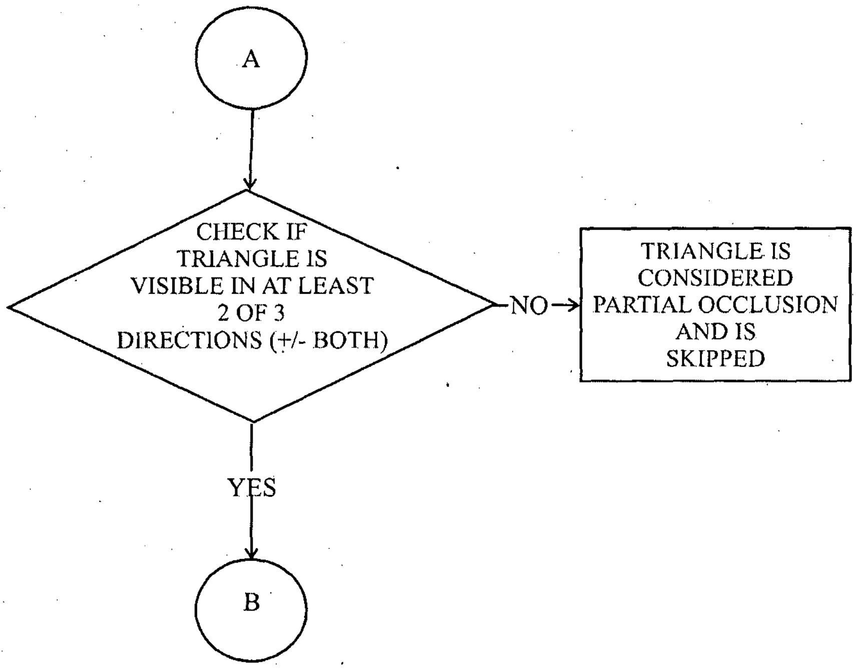
A
CHECK IF TRIANGLE IS VISIBLE IN AT LEAST 2 OF 3 DIRECTIONS (+/- BOTH)
NO
TRIANGLE IS CONSIDERED PARTIAL OCCLUSION AND IS SKIPPED
YES
B

FIGURE 3

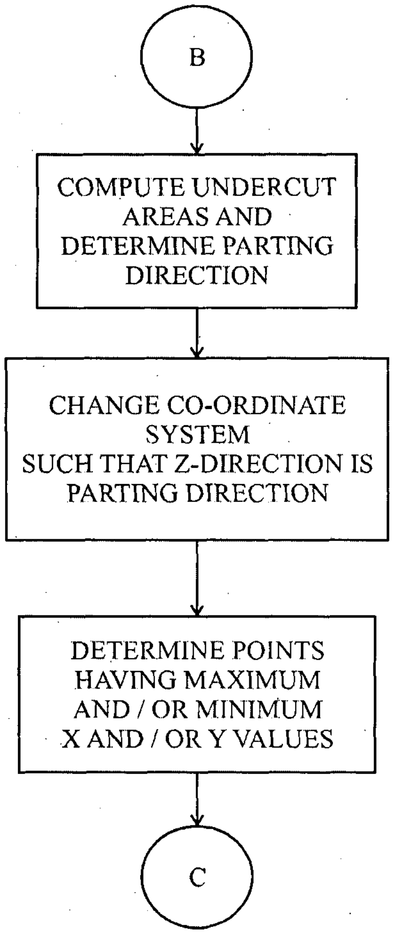
B
COMPUTE UNDERCUT AREAS AND DETERMINE PARTING DIRECTION
CHANGE CO-ORDINATE SYSTEM SUCH THAT Z-DIRECTION IS PARTING DIRECTION
DETERMINE POINTS HAVING MAXIMUM AND / OR MINIMUM X AND / OR Y VALUES
C

FIGURE 4

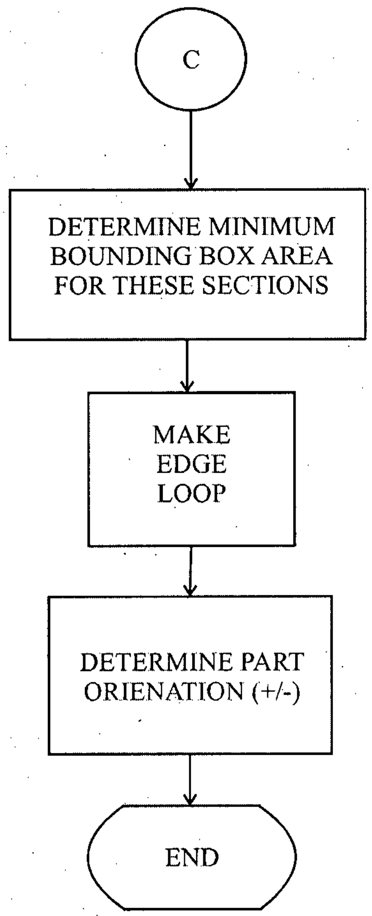
C
DETERMINE MINIMUM BOUNDING BOX AREA FOR THESE SECTIONS
MAKE EDGE LOOP
DETERMINE PART ORIENATION (+/-)
END

FIGURE 5

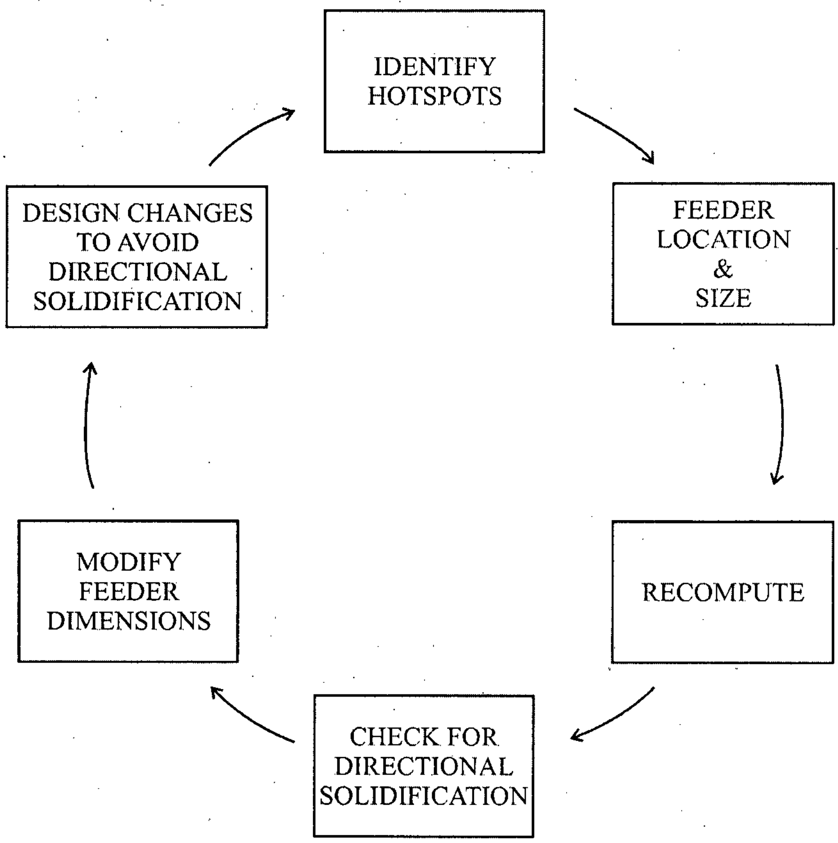
IDENTIFY HOTSPOTS
FEEDER LOCATION & SIZE
RECOMPUTE
CHECK FOR DIRECTIONAL SOLIDIFICATION
MODIFY FEEDER DIMENSIONS
DESIGN CHANGES TO AVOID DIRECTIONAL SOLIDIFICATION

FIGURE 6

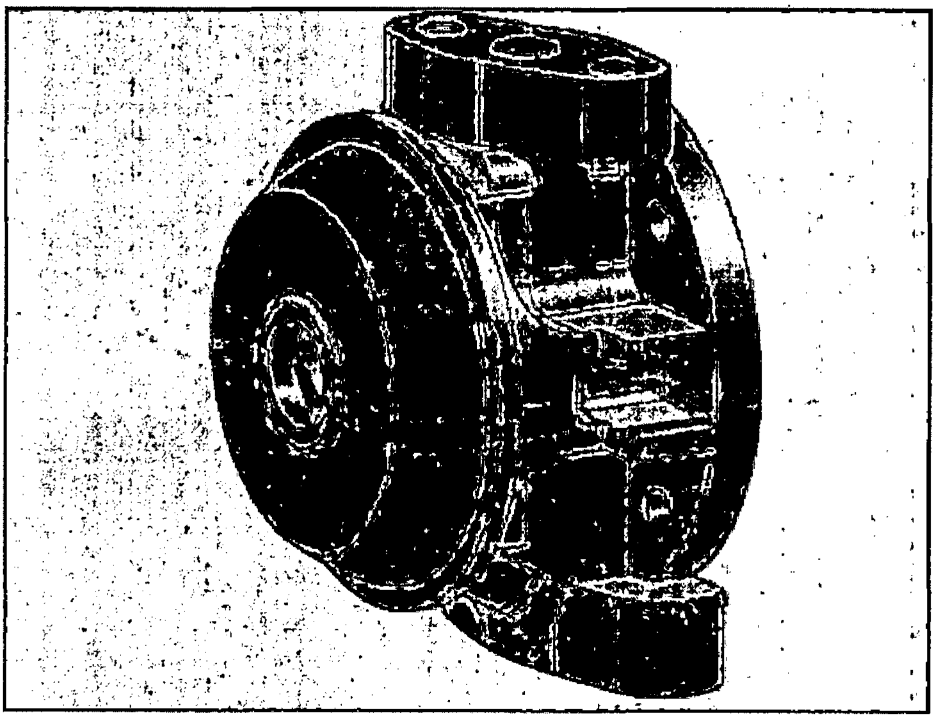

FIGURE 7

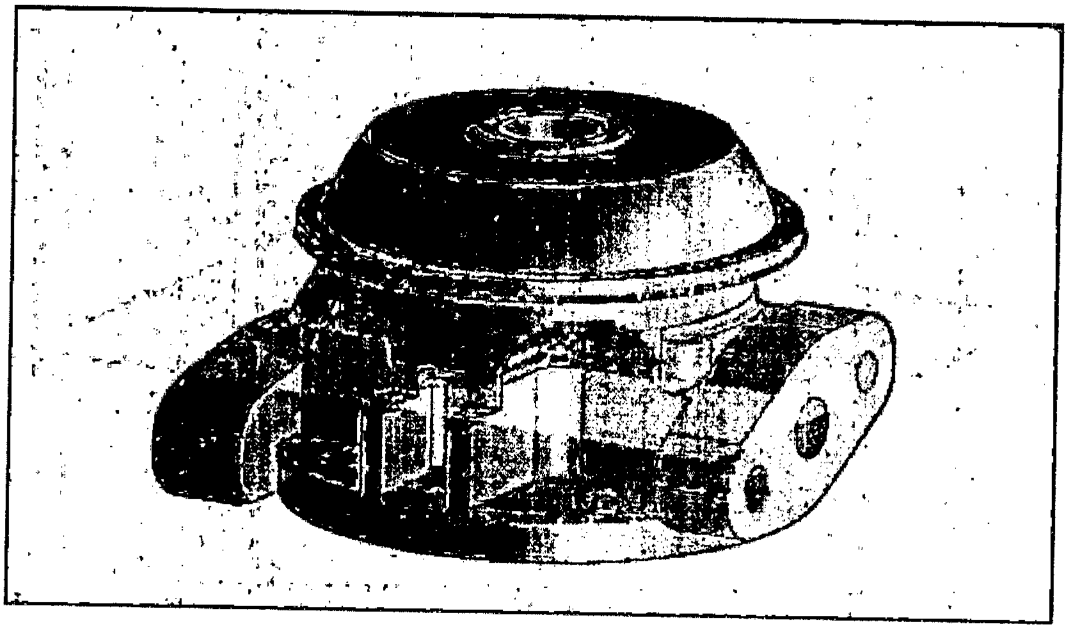

FIGURE 8

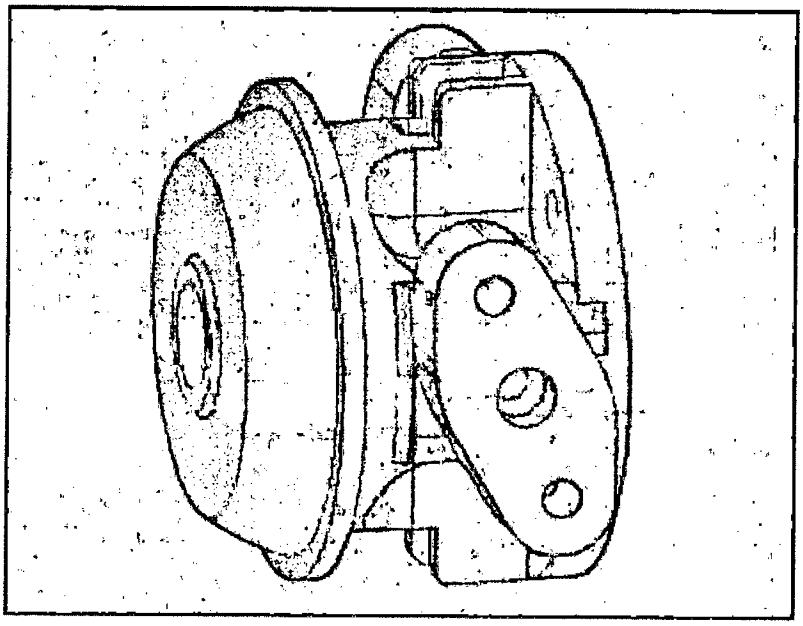

FIGURE 9

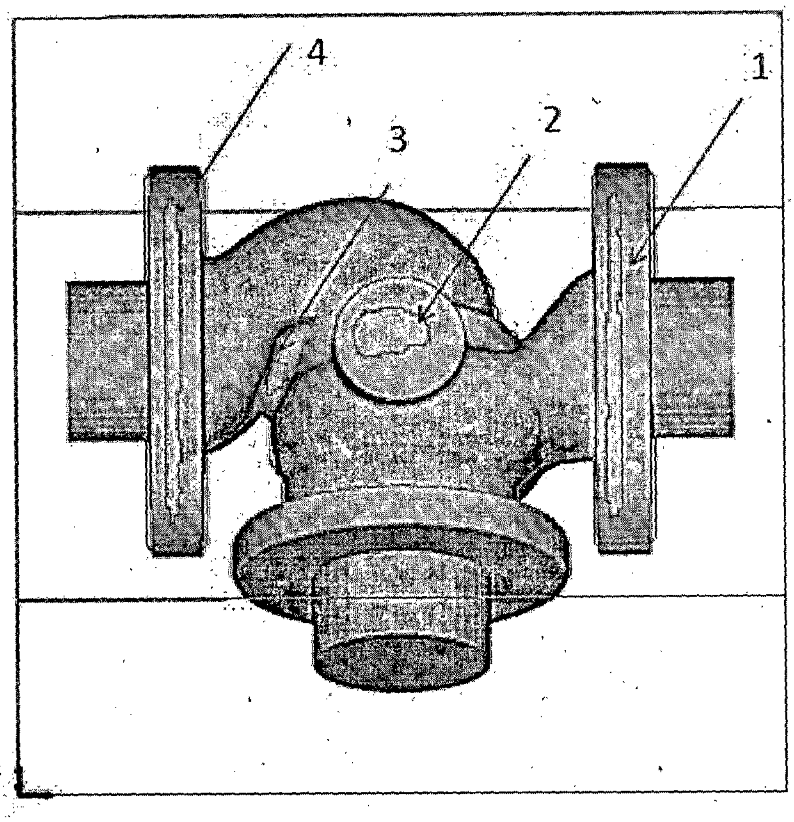

FIGURE 10

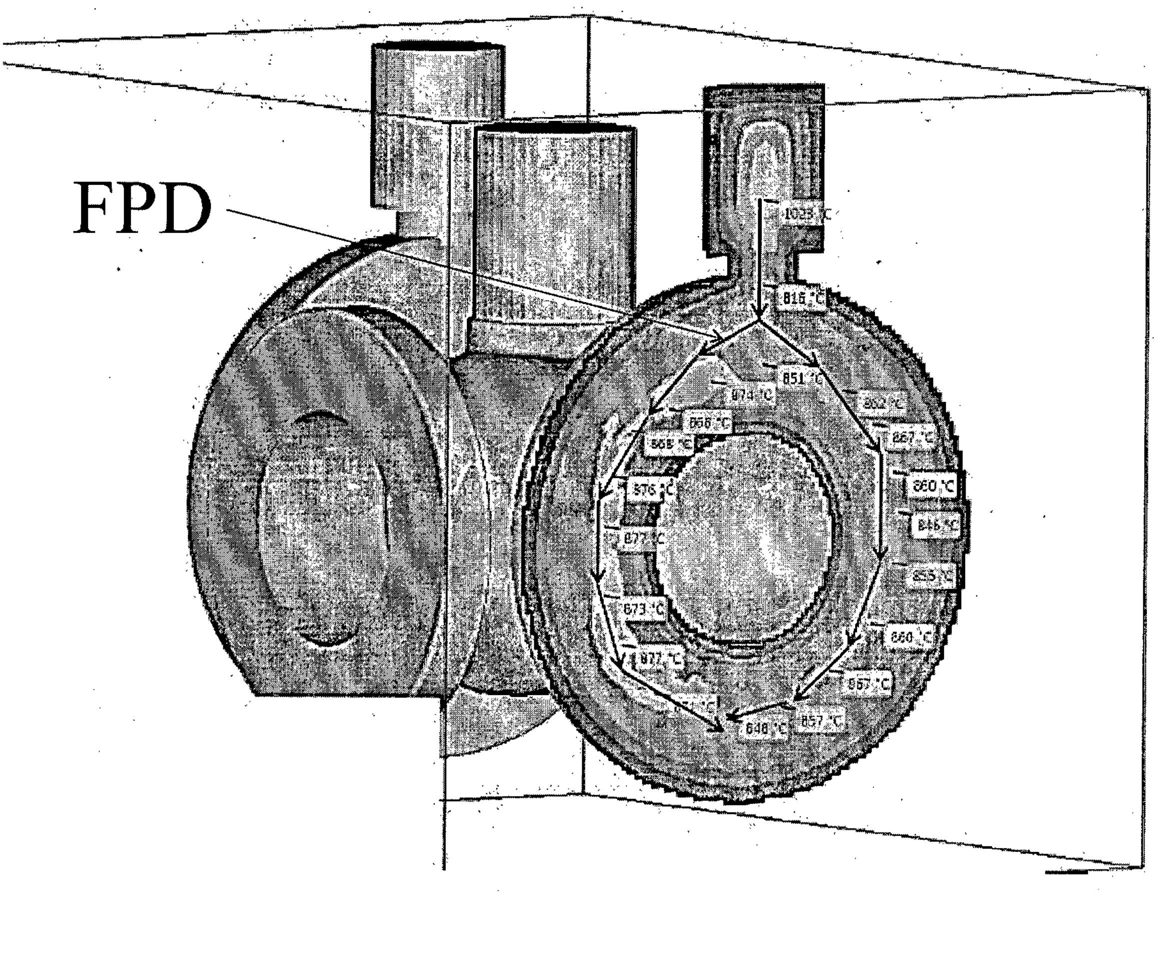

FIGURE 11