from the deformations of the shaft or of the cutting disk support, the cutting head or the shaft of the cutting head, when measuring the different boring parameters.

Regardless of the proposed methods, the pilot must systematically deduce, from the values measured by the different sensors, the conditions imposed by the ground being penetrated and adjust different characteristics of the tunnel boring machine (speed of advance, torque, etc.) as a function of these values. This adjustment must, however, take into account the type of tunnel boring machine used, and therefore requires considerable expertise on the part of the pilot. Moreover, the nature of the ground is not generally homogeneous, so that the values obtains may not be representative of the true nature of the ground at the tunnel face.

SUMMARY

One object of the present disclosure is therefore to propose a method for optimizing the characteristics of a tunnel boring machines, in particular a slurry pressure or variable density type tunnel boring machine, which allows optimizing in real time the characteristics of the tunnel boring machine so as to improve boring without risking damaging the tunnel boring machine, regardless of the nature of the ground at the tunnel face or even the type of tunnel boring machine used.

To this end, in a first aspect, the present disclosure proposes a method for determining a ground/machine interaction model during boring of a ground by a tunnel boring machine, in particular a tunnel boring machine of the slurry pressure or VD (Variable Density) type, said method comprising the following steps:

- S1: obtaining, by a processing unit, a set of boring parameters characterizing a bore by at least one given tunnel boring machine over at least one boring site, particularly a tunnel boring machine of the slurry pressure or VD type, said set comprising parameters obtained by sensors;
- S2: identifying, by the processing unit, a set of formulas depending on all or part of the boring parameters,

– S3: determining, by the processing unit, a set of variables based on the formulas thus identified,

– S4: applying, by the processing unit, a non–supervised classification algorithm to the variables so as to obtain groups of individuals identified according to a predefined criterion of said algorithm,

– S5: applying, by the processing unit, a supervised classification algorithm to the variables and the groups of individuals thus determined so as to obtain a ground/machine interaction model connecting said variables to said groups.

Certain preferred but non–limiting features of the method for determining an interaction model described above are the following taken individually or in combination:

– the non–supervised classification comprises a segmentation (clustering) algorithm, for example a K–MEANS algorithm.

– the supervised classification comprises a random forest algorithm.

– the variables depend on at least one of the following boring parameters: a torque of a cutting wheel of the given tunnel boring machine, a speed of rotation of the cutting wheel of the given tunnel boring machine, a speed of advance of the given tunnel boring machine, a contact force of the given tunnel boring machine, a surface area of the cutting wheel of the given tunnel boring machine, a radius of the cutting wheel of the given tunnel boring machine, a confinement pressure at the axis of the given tunnel boring machine.

– the step S4 consisting of non–supervised classification determines between 8 and 10 different groups of individuals.

– each variable describes a ground segment, such as a given ring deposited by at least one given tunnel boring machine, on at least one boring site and in which the groups of individuals determined in step S4 correspond to groups of ground segments, particularly groups of rings deposited by at least one given tunnel boring machine on at least one boring site.

According to a second aspect, the present disclosure also proposes a method for optimizing the characteristics of a tunnel boring machine, particularly a tunnel boring machine of the slurry pressure or VD type, said method comprising the following steps:

- S0: determining, by the processing unit, a ground/machine interaction model according to the first aspect,
- S11: instantaneous measurement, by the processing unit, of the set of specific boring parameters of the tunnel boring machine,
- S13: determining, by the processing unit, the group of individuals corresponding to the boring parameters measured in step S11 by means of the ground/machine interaction model,
- S14: ~~optimizing~~modifying, by the processing unit, the characteristics of the tunnel boring machine as a function of the group of individuals thus determined.

Certain preferred but non–limiting features of the optimization method above are the following, taken individually or in combination:

- the optimization method also comprises, prior to step S13, a step consisting of calculating all or a part of the variables determined in step S3 based on the boring parameters measured in step S11, and wherein, during step S13, the group of individuals is determined by applying the ground/machine interaction model and to the variables thus determined and/or
- during boring, the tunnel boring machine successively deposits a plurality of rings, and the steps S11 to S14 are repeated during the deposit of each ring.

According to a third aspect, the present disclosure also proposes a computer program product comprising code instructions for executing a method for determining a ground/machine interaction model during boring of a ground by a tunnel boring machine, particularly a tunnel boring machine of the slurry pressure or VD type as described above and/or a method for

CLAIMS

1. A method (S0) for determining a ground/machine interaction model during boring of a ground by a tunnel boring machine, in particular a tunnel boring machine of the slurry pressure or VD (Variable Density) type, said method comprising the following steps:

– S1: obtaining, by a processing unit, a set of boring parameters characterizing a bore by at least one given tunnel boring machine over at least one boring site, particularly a tunnel boring machine of the slurry pressure or VD type, said set comprising parameters obtained by sensors;

– S2: identifying, by the processing unit, a set of formulas depending on all or part of the boring parameters,

– S3: determining, by the processing unit, a set of variables based on the formulas thus identified,

– S4: applying, by the processing unit, a non–supervised classification algorithm to the variables so as to obtain groups of individuals identified according to a predefined criterion of said algorithm,

– S5: applying, by the processing unit, a supervised classification algorithm to the variables and to the groups of individuals thus determined so as to obtain a ground/machine interaction model connecting said variables to said groups.

2. The method (S0) according to claim 1, wherein the non–supervised classification comprises a segmentation ~~(clustering)~~ algorithm, for example a K–MEANS algorithm.

3. The method (S0) according to one of claims 1 or 2, wherein the supervised classification comprises a random forest algorithm.

4. The method (S0) according to one of claims 1 to 3, wherein the variables depend on at least one of the following boring parameters: a torque of a cutting wheel of the given tunnel boring machine, a speed of rotation of the cutting wheel of the given tunnel boring machine, a speed of advance of the given tunnel boring machine, a

contact force of the given tunnel boring machine, a surface area of the cutting wheel of the given tunnel boring machine, a radius of the cutting wheel of the given tunnel boring machine, a confinement pressure at the axis of the given tunnel boring machine.

5. The method (S0) according to one of claims 1 to 4, wherein the non–supervised classification step S4 determines between 8 and 10 different groups of individuals.

6. The method (S0) according to one of claims 1 to 5, wherein each variable describes a ground segment, such as a given ring deposited by at least one given tunnel boring machine, on at least one boring site and wherein the groups of individuals determined in step S4 correspond to groups of ground segments, particularly groups of rings deposited by at least one given tunnel boring machine on at least one boring site.

7. A method (S10) for optimizing the characteristics of a tunnel boring machine, particularly a tunnel boring machine of the slurry pressure or VD type, said method comprising the following steps:

– S0: determining, by the processing unit, a ground/machine interaction model according to one of claims 1 to 5,

– S11: instantaneous measurement, by the processing unit, of the set of specific boring parameters of the tunnel boring machine,

– S13: determining, by the processing unit, the group of individuals corresponding to the boring parameters measured in step S11 by means of the ground/machine interaction model,

– S14: ~~optimizing~~ modifying, by the processing unit, the characteristics of the tunnel boring machine as a function of the group of individuals thus determined.

8. The method (S10) according to claim 7, also comprising, prior to step S13, a step (S12) consisting of calculating, by the processing unit, all or a part of the variables determined in step S3 based on the boring parameters measured in step S11, and wherein, during step S13, the group of individuals is determined by applying the ground/machine interaction model and to the variables thus determined.

9. The method (S10) according ~~to one of claims 7 or 8~~to claim 7, wherein, during boring, the tunnel boring machine successively deposits a plurality of rings, and the steps S11, S13 ~~to~~and S14 are repeated during the deposit of each ring.

10. A computer program product comprising code instructions for executing a method (S0) for determining a ground/machine interaction model during boring of a ground by a tunnel boring machine, particularly a tunnel boring machine of the slurry pressure or VD type, according to one of claims 1 to 6 and/or a method (S10) for optimizing the characteristics of a tunnel boring machine, particularly a tunnel boring machine of the slurry pressure or VD type, according to one of claims 7 to 9.

11. Storage means readable by data processing equipment on which a computer program product comprises code instructions for the execution of a method (S0) for determining a ground/machine interaction model during boring of a ground by a tunnel boring machine, particularly a tunnel boring machine of the slurry pressure or VD type, according to one of claims 1 to 6, and/or a method (S10) for optimizing the characteristic of a tunnel boring machine, in particular a tunnel boring machine of the slurry pressure or VD type, according to one of claim 1 to 6 and/or a method (S10) for optimizing the characteristics of a tunnel boring machine, particularly a tunnel boring machine of the slurry pressure or VD type, according to one of claims 7 to 9.